The Tec 6 vaporizer: Why desflurane needs to be heated

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The Ohmeda Tec 6 was designed as an agent-specific vaporizer for desflurane. Its exterior framework offers some unique features. Aside from its unique filling port, broad calibration range, and additional light-emitting diodes (LEDs), its large size literally sets it apart from all other models. As distinctive as the exterior appears, its interior design is even more unconventional; that is, it is not a variable-bypass, flow-over system. There are no mixing chambers, baffles, or temperature-sensing bellows; a differential pressure transducer system takes their place. Many modifications were made primarily to accommodate the remarkably high vapor pressure of desflurane. This is especially true in regard to the sump heating unit. Although there are many options to accommodate a high vapor pressure, a heating unit serves the purpose best. A brief review of vaporization and fundamental thermodynamics will demonstrate why this is so.

Key words: Anesthetic equipment, desflurane, vaporizer.

Introduction
Desflurane was originally developed as 1653 in the early 1970s. According to a conversation with the Desflurane Product Manager, D.L. Roccoberton in March 1994, desflurane later gained renewed interest that led to promising clinical trials in 1986.

Since 1986, anesthesia care providers have been awaiting the release of this new nonflammable methyl ethyl ether, which possesses some very attractive physical qualities. Its low blood:gas partition coefficient of 0.42 at 37°C offers the advantage of quick anesthetic induction. Because tissue: blood coefficients are quite similar to blood:gas coefficients, desflurane also allows for rapid emergence.

Desflurane became clinically available in September 1989. It has a vapor pressure of 681 mmHg at 20°C, which requires a modified vaporizer to accurately deliver the agent. Development of such a vaporizer began in 1989, and the Tec 6 vaporizer was the result.

A review of vaporization and fundamental thermodynamics will show the relationship between vapor pressure and vaporizer construction.

Review of thermodynamics and vaporization

If anesthetics were stored on the anesthesia machine as gases, their container size would be cumbersome. Therefore, all inhaled anesthetics are in liquid form within their vaporizers. According to the second law of thermodynamics, molecules escape from the liquid state to the gaseous state inside a closed container until equilibrium is reached. For the molecules to be transformed from a liquid to a gas, they must reach a specific energy level.

The latent heat of vaporization is the amount of heat that must be added to convert a liquid to a gas. Heat is a transient phenomenon that occurs as energy is being transferred from one sys-
tem to another when a temperature gradient exists. It is measured as energy crosses the boundary between the two substances.

In the case of vaporization, the energy takes the form of the random motion of molecules and heat is measured as the energy is transferred between the liquid and gas. According to an October 1993 letter from L.G. Jeroszko, a physical engineer, applying heat will add kinetic energy to the liquid and allow more molecules to escape in the form of gas.

**Kinetic energy** (KE) is proportional to the mass and velocity of a substance. Velocity is a very important factor, as shown by the equation, KE = \( \frac{1}{2}mv^2 \) (i.e., \( m = \) mass and \( v = \) velocity).

In an anesthetic liquid, the molecules at the surface move faster and easily escape into the gaseous form.

In the gaseous state, the molecules move very rapidly, and some may even revert to liquid form within a closed container (i.e., in the vaporizer). Once equilibrium has been achieved, the vapor pressure can be measured as the gas molecules bombard the walls of the closed container. The addition of heat to the system will increase the vapor pressure.

In an open container, the liquid-gas relationship changes, such as when a vaporizer is turned on. The liquid loses more and more kinetic energy as the molecules escape. The molecules with the greatest kinetic energy escape first, leaving behind those with a lower kinetic energy. Hence, the average kinetic energy of the remaining liquid is lower. This causes the liquid to cool.

A practical example of this occurs when soup gets cold as it evaporates. **Evaporation** is simply the vaporization of a liquid to a gas, which takes place below its boiling point. The loss of heat that occurs with this phenomenon is known as **evaporative cooling**. Likewise, volatile anesthetics cool as they vaporize. As has been well documented, ether can actually form ice crystals during the drop cloth method, because its heat dissipates quickly during vaporization.

**History**

Vaporizer design is based on providing optimal vaporization of the liquid anesthetic. There are many options available to increase vaporization at the liquid-gas interface. These include manipulation of variables such as changing atmospheric pressure, relative humidity, air circulation, surface area, or intermolecular bonds.

The strategy employed in the Tec 6 involves an increase in the volatile agent's temperature by adding heat (energy). As described above, an anesthetic will cool as it vaporizes. This cooler liquid will draw energy from its external surroundings to maintain a constant temperature (i.e., constant kinetic energy). Applying heat adds kinetic energy to the liquid so more molecules can escape into the gaseous form.

Conventional vaporizers are made of materials with high thermal conductivity (i.e., measure of heat flow) and high specific heat (i.e., amount of energy required to raise the temperature of a given quantity of a substance by 1°C). A high **thermal conductivity** enables the vaporizer itself to transfer heat from the ambient environment into its contents at a rate sufficient to prevent molecules from falling short of energy needs. This action occurs as long as a sufficient temperature gradient exists. In addition, materials with a high specific heat maintain a more stable temperature and heat distribution.

With most volatile anesthetics, the vaporizer construction is capable of allowing enough heat to transfer from the ambient environment to support the latent heat requirements. This is possible because the average vapor pressure of commonly used anesthetic gases is only about 200 mmHg.

The rate of evaporative cooling (i.e., lowering of molecular energy) is proportional to the vapor pressure and the latent heat. A substance with an extremely high vapor pressure will evaporate quickly and therefore cool and lose energy very rapidly. It stands to reason that the greater the vapor pressure, the greater the latent heat of vaporization. An anesthetic with a vapor pressure of approximately 200 mmHg can keep up with its loss of energy by heat conduction through the vaporizer. However, desflurane's latent heat of vaporization exceeds the conventional energy requirements. Compared to the vapor pressure of halothane, enfurane, and isoflurane (243, 175, and 238 mmHg, respectively), desflurane's vapor pressure of 681 approximately triples these conventional volatile anesthetics.

**Discussion**

Conventional vaporizers are classified as variable-bypass, flow-over, temperature-compensated, and out-of-circuit systems. Within the vaporizer, the fresh gas mixture diverts through a number of chambers (variable-bypass), flows over the agent (flow-over), and helps to expand or contract the temperature-sensing bellows (temperature-compensated). The vaporizers are located outside the patient breathing system (out-of-circuit). A concentration dial and rotary valve determine the amount of agent that will join with the fresh gas.
flow before the gases exit the vaporizer outlet en-route to the patient.4

The Ohmeda Tec 6 was designed as an agent-specific, temperature-constant, electronically pressure-constant, out-of-circuit vaporizer for desflurane. There are a few unique physical characteristics of the Tec 6 that may be a bit perplexing initially. The first peculiarity noticed about the vaporizer is that it is much larger than other models. It was constructed with a large-capacity sump capable of holding approximately 400 mL, plus a nominal 60 mL reserve that is not indicated on the level display.

The Tec 6 capacity sump of nearly two bottles was selected because of desflurane's low potency compared to other anesthetic agents. This working volume will allow for administration of several hours of anesthesia before refilling is required, especially when low flows are utilized. One innovative feature of the Tec 6 enables refilling while the vaporizer is in use, a feature known as “filling-on-the-fly.”

For a healthy adult, 18-60 years old, the minimum alveolar concentration of desflurane is 6 to 7.3%.3 This is why the Tec 6 has a broad calibration range (i.e., 1-18%). Because a nitrous oxide-oxygen-desflurane combination could inadvertently deliver a hypoxic gas mixture (e.g., 70% nitrous oxide and 18% desflurane), a safety feature stops the concentration dial at 12%. A dial release must then be depressed in order to turn the concentration higher.

The filler port was specifically developed to accept the crimped-on SAF-T-FILL® valve of the plasticcoated desflurane bottle. This system offers some distinct advantages and corrects some obvious shortcomings noted in previous models. The filling system prevents inadvertent filling with the wrong agent. The bottle probe actually inserts directly into the filler port. An “O” ring fitted on the spring-loaded bottle cap helps engage and seal the opening before liquid can flow, which aids in preventing spillage and operating room contamination.6 If a standard glass bottle was used, there would be an unacceptable amount of desflurane lost to the environment through immediate vaporization when the top was unscrewed or if the bottle was dropped and broken. This would further pollute the surroundings as well as waste the agent.

The Tec 6 also has several light-emitting diodes (LEDs). The no-output LED will illuminate under the following conditions: the desflurane level is less than 20 mL, the vaporizer it tilted, a power failure occurs, or an internal malfunction develops. An audible alarm will warn of these conditions.

When the power cord is plugged in, the warm-up LED will appear as amber. The vaporizer will then perform a self-test, and a warning alarm will ring for 1 second. This self-test can be repeated any time the anesthesia provider wishes by pressing the mute button for 4 seconds. When the liquid in the unit reaches 39°C, the operational LED will appear as green. Once the unit is plugged in, it should remain plugged in to keep the liquid desflurane at this constant temperature.10

Internal design

Desflurane has a vapor pressure of 681 mmHg, so it vaporizes very rapidly and also cools quickly. Consequently, without a heat source, its molecular movement slows to the point where its kinetic energy is too low to allow adequate vaporization. Under these circumstances, it cannot get heat from the environment at a rate sufficient to replace energy lost during vaporization. It will quickly reach equilibrium at a very low energy level, minimizing further vaporization.

There are many options for increasing the vaporization at the liquid-gas interface. Most techniques would be difficult within the vaporizer unit. Other vaporizer design concepts were initially considered, such as increasing surface area and air circulation. The mechanisms needed to do so require more space than the mechanisms needed to heat liquids.

According to an August 1993 letter from Desflurane Product Manager D.L. Roccoberton, the engineering goal was to design a desflurane vaporizer that would interlock in series with the Tec 4 and Tec 5 vaporizers on the Ohmeda Selecta
tec® backbar. Adjustment of temperature proved to be the most practical and cost-effective alternative for improved vaporization while maintaining a workable size and allowing machine interface.

D.L. Roccoberton also informed me that several performance tests at various temperatures found that 39°C is the optimal temperature to enable consistent flow, given various operating room temperatures. If the temperature of the desflurane liquid is raised to 39°C, a 1,500 mmHg vapor pressure will be generated. This vapor pressure is sufficient to provide an adequate supply of desflurane for mixture within the range of clinically used gas flows.

This 1,500 mmHg vapor pressure necessitates an adjustment of the internal workings of the Tec 6. It is assembled with a differential pressure transducer that measures the pressure difference between the fresh gas flow and the vapor pressure of the agent. This pressure transducer system is redundant, according to Roccoberton, because a sec-
ondary transducer monitors the primary transducer. If the transducer fails, the vaporizer shuts off and an alarm sounds to alert the user.

The control electronics maintain a zero pressure difference across the transducer through an output pressure regulating valve. As with other vaporizer models, the concentration dial can then accurately control the flow of anesthetic gas into the main gas stream.9(p11)

Recently, an Ohmeda investigative team discovered a few vaporizers manufactured prior to August 1, 1993, that had dysfunctional control valves. At high flows and concentrations, these vaporizers deliver higher concentrations of the anesthetic than are indicated by the vaporizer dial setting. This discrepancy may not be detected by the internal alarms.

To remedy the problem, in a July 1994 letter, Ohmeda Regulatory Affairs Manager R.T. Riddle said that Ohmeda recommends a maximum vaporizer dial setting of 6% at flow rates of 4 L/min and 9% for flow rates of 3 L/min or less. Ohmeda also recommends using an agent monitor and ensuring that external contaminants are not used on the vaporizer or on the filling port of the agent bottle. Reports received to date have not involved patient injury.

A potential fresh gas leak originating in the manifold on several of these units was also noted. If a leak develops during use, Ohmeda recommends that the dial-release button be fully depressed and released. This may dislodge the internal plunger of the manifold valve from the flow-control holes of the valve body. If the leak continues, the patient should be disconnected from the anesthesia machine and ventilated with a manual resuscitator so that the anesthesia machine can be repaired or exchanged. Finally, because of these potential problems, proper preoperative checkout procedures, which are described in the Ohmeda Tec 6 Operation and Maintenance Manual, should be followed before each use.

The Tec 6 differs from other agent-specific vaporizers in several ways, as illustrated in Figures 1 and 2. First, it is not a variable-bypass or a flow-over system. There is simply a vaporizing chamber with an electric heater and an output opening that is controlled by the differential pressure transducer. No fresh gas is bypassed through this chamber.

Figure 1
Schematic of the gas flow through a conventional Ohio vaporizer

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Figure 2
Schematic of gas flow through the Tec 6 vaporizer

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Another difference is the absence of a mixing chamber within the Tec 6. Conventional models are built with distinct mixing chambers as well as protective baffles to guard against spillage of liquid agent into adjacent chambers. By contrast, desflurane vapor joins with fresh gas flow in the common manifold, and both exit through the common gas outlet. Therefore, tilting the Tec 6 does not render it inoperative or dangerous to operate.11

All conventional vaporizers experience small output decreases when the carrier gas is changed from 100% oxygen to air or nitrous oxide.10,13,22 The performance of the Tec 6 vaporizer at a constant dial setting with a change in carrier gas closely resembles that of conventional vaporizers.

Vaporizer output is highest when oxygen is the carrier gas and lowest when nitrous oxide is the carrier gas. This effect is accentuated at low fresh gas flows and correlated with carrier gas viscosity. However, conventional vaporizers demonstrate transient peaks and valleys in anesthetic output when the carrier gas is altered. Because the fresh gas mixture is not bypassed through the Tec 6, the desflurane vaporizer does not demonstrate these conventional idiosyncratic extremes in output.12

**Summary**

As demonstrated, the Ohmeda Tec 6 was designed as an agent-specific, temperature-constant, electronically pressure-constant, out-of-circuit vaporizer for desflurane, whose internal and external design varies markedly from those of conventional vaporizers. There are no mixing chambers, baffles, wicks, or temperature-sensing bellows, because it is not a variable-bypass, flow-over system.

A conventional vaporizer is completely unsuitable for desflurane because of its vapor pressure. The differential pressure transducer, control electronics, and pressure-regulating valve are adaptive devices that are necessary to allow accurate delivery of desflurane, while the sump heating unit maximizes vaporization and mixing of desflurane with fresh gas flow.

The exterior layout of the Tec 6 was designed with additional LEDs to assist in the safe delivery of desflurane. A large capacity sump provides additional hours of anesthesia before refilling is necessary. Its agent-specific filler port provides pollution-free refilling with the advantage of filling on the fly.

The Tec 6 design may seem peculiar at first, but with a little hands-on experience, most anesthetists will find that it is easier and safer to manage than its predecessors.

**REFERENCES**


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Diane Miller, RN, MHS, graduated from the Anesthesia for Nurses Program at the Medical University of South Carolina in August 1994. Born and raised in Buffalo, New York, she received her BSN at the State University of New York at Buffalo in 1987. She is presently employed at Natividad Medical Center in Salinas, California.

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