lated $V_a - (TV - RDS)RR$; where V_a is alveolar ventilation; *TV*, tidal volume; *RDS*, respiratory dead space, and *RR*, respiratory rate.

The respiratory rate, tidal volume, and minute volume were measured using a Collins 9.5-liter spirometer and a permanent record made.

The respiratory rate was not changed by either schedule. The minute volume, tidal volume, and alveolar ventilation were significantly depressed by both drug schedules. These same parameters demonstrated differences between the schedules applied. The differences were evaluated by analysis of variance and were found to be statistically significant: $(0.05 < P > 0.01)$ for the 5 per cent level, $(0.01 < P > 0.001)$ for the 1 per cent level. Greater depression was produced by meperidine alone.

The sedative effect of both drug schedules was the same. There was less respiratory depression of the patients who received propiomazine in addition to the meperidine. This was an interesting and unexpected finding. The spirometer tracings gave no indication of irregularity or of variations during the breathing tests. Since there is little in the literature about the effects of propiomazine, this brief report is made to indicate further lines of investigation which may be followed.

The views and opinions expressed herein do not necessarily represent those of the Surgeon General, The Department of The Army, or the Department of Defense.

GADGETS

New Vaporizer for Volatile Agents

Dr. James A. Felts of Herrin Hospital in Herrin, Illinois, and the Holden Hospital, Carbondale, Illinois, has devised a new vaporizer for use with volatile anesthetic agents. This vaporizer, and its earlier models, has been in use since March, 1960. It is designed for a technique, to be described fully in a separate paper, in which diethyl ether or halothane are intermittently injected in true closed circuit anesthesia, using metabolic flows of oxygen. In this technique, diethyl ether or halothane are admitted to the vaporizer by syringe in closely controlled increments related to the patient's body weight and to the time elapsed. Succinylcholine chloride is simultaneously administered by intravenous drip, also in amounts related to the patient's body weight and to the time elapsed. The vaporizer is not limited to this particular technique, however. Any volatile agent may be used, if it is adaptable to a closed system. The device is coupled to the exhalation port of the anesthesia apparatus.

The vaporizer, shown in side view in figure 1, consists of a base through which the exhaled atmosphere passes, a vaporizing core, and a surrounding jacket. Figures 2 and 3 are cross sections through portions of the base.

With the exception of the two adapters, one for coupling to the anesthesia machine (*A* in figure 1), and one for attachment of the exhalation tubing (*B* in figure 1), the apparatus is made of copper, taking advantage of the superior heat transfer properties of this metal. The adapters, since they are subject to stress and manipulation, are made of more durable brass.

The passage in the base, through which the exhaled atmosphere flows, consists of two chambers, shown in figure 1 as *C* and *D*. The chamber nearest the patient (*C*) is a high

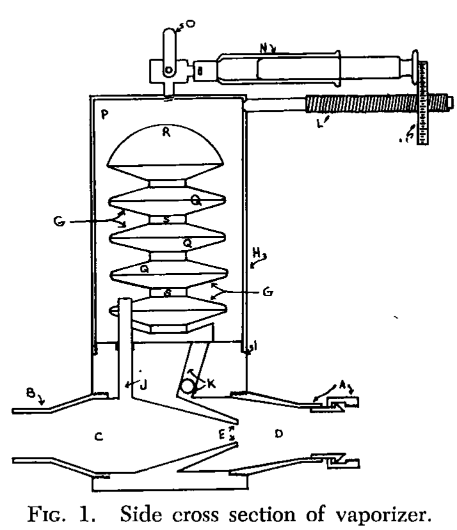

FIG. 1. Side cross section of vaporizer.

pressure chamber, and the one nearest the anesthesia apparatus (*D*) is a low pressure chamber. These pressure differentials in the exhalation passage are created by application of Bernoulli's Principle. The best known application of the principle, the Venturi jet, is used at *E* (fig. 1) in the low pressure chamber.

Bernoulli's Principle states that, as a result of the Law of Conservation of Energy, a fluid passing through a conduit at a given rate of flow exerts a lowered pressure against the walls of the conduit at constrictions, where its velocity is increased, and an increased pressure against the walls at enlargements, where its velocity is reduced.

In this device, passage of the exhaled atmosphere through enlarged chamber *C* reduces its velocity and increases its pressure. Passage through the constriction in the Venturi (*E*) increases the velocity and produces a reduced pressure in chamber *D*.

At the flow rates encountered in human expirations, these pressure changes are not great. A major limitation is the need to maintain a relatively large cross-sectional area in the Venturi portion. This minimizes expiratory resistance, but also reduces velocity. However, by coupling the high and low pressure chambers together through a bypass, a pressure differential in the order of 3 mm. of

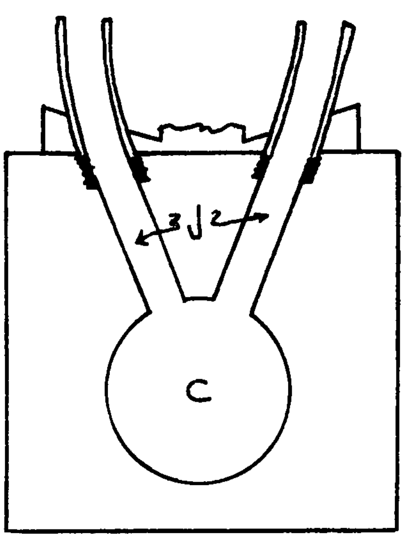

Fig. 2. Enlarged section through chamber *C*.

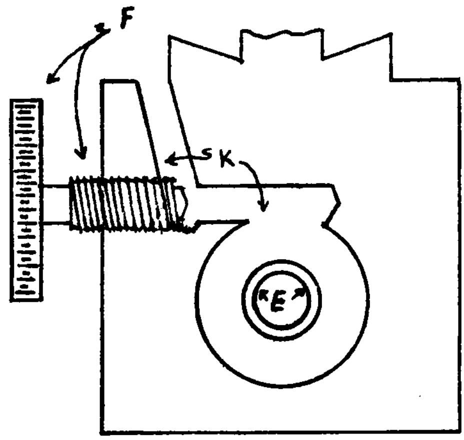

Fig. 3. Enlarged composite section through *E* and duct *K*.

mercury can be created between the two chambers. This differential is sufficient to cause the circulation of a substantial amount of the exhaled atmosphere through the bypass, in this case the vaporizing chamber (*P*). A valve (*F* in figure 3) limits or shuts off this circulation.

The vaporizing chamber contains a copper core, (*S*) which is continuous with the base of the vaporizer, being machined from the same piece of metal. The core consists of a central shaft and a series of concentric sloping fins (*Q*), surmounted by a hemispherical dome (*R*). This geometerical shape provides a large vaporizing surface within a small space. In the model shown, the core contains a surface area of 135 sq. cm. in a length of 7 cm. and a diameter of 4 cm. The core and vaporizing space are enclosed by a copper jacket (*H*) which is attached to the base of the vaporizer by a threaded joint (*I*). Centered in the top of the jacket is a right-angle stopcock (*O*) which will accommodate a syringe (*N*), for injection of the anesthetic agent. A threaded shaft (*L*) is mounted parallel to the syringe. A knob (*M*) on its end contacts the plunger of the syringe. As the knob is turned, the plunger is slowly advanced, so that fractions of cubic centimeters can be injected.

The volatile agent is injected in small increments from the syringe, drops to the hemispherical dome, and flows over the surfaces (*G*) of the vaporizing core (*S*). All surfaces are available for vaporization, since the agent will flow on the undersides of the fins.

All currently used volatile anesthetics will flow underneath on a slope which is pitched 10 degrees from the horizontal. The vaporizer shown is equipped with 18 degree slopes in the assumption that, in actual use, it will seldom be mounted perfectly plumb. The greater slope allows free flow under these conditions. As the agent is converted to vapor, it is combined with the gasses circulating into the vaporizing chamber via ducts *J* (figs. 1 and 2) as a result of the higher pressure created in chamber *C*, and is carried into the closed system through the outlet duct *K* (figs. 1 and 3), as a result of the low pressure created in chamber *D*.

The vaporizer shown in the illustrations measures 6 inches (15 cm.) in over-all height, and 2½ inches (6.5 cm.) in jacket diameter. This size has the capacity to vaporize diethyl ether and halothane far more rapidly than any prudent clinical use would demand. A unit of this size will vaporize up to 5 cc. of methoxyflurane per hour. This volume, in a true closed system, has been enough to maintain stage 3, plane 2 anesthesia in patients of 180 pounds (82 kg.) of body weight. A unit with a larger core may be required for deeper methoxyflurane anesthesia or for robust patients. Such a vaporizer could easily be manufactured without markedly increasing the diameter of the jacket.

Heat for vaporization is supplied from three sources. Some heat is absorbed from room air by the jacket (*H*) and is conducted to the core through the threaded joint. Some heat is absorbed from the warm expired atmosphere, and conducted to the core from the base of the vaporizer. A substantial amount of heat is gained from the condensation of small amounts of water in the base of the vaporizer. This condensation, amounting to about 1 cc. per hour, is not troublesome, and is a heat source of importance. At 20 C., the condensation of 1 cc. of water yields 585 calories, enough to vaporize 8.98 cc. of diethyl ether at that temperature. In practice, even with the rapid vaporization of ether, the maximum temperature drop in the vaporizing chamber has been 4 degrees F., (2.2 degrees C.).

This vaporizer, then, provides a large vaporizing surface within a small space, for the rapid vaporization of injected increments of volatile anesthetics in a closed system. Because of the excellent heat transfer properties of copper, and because of multiple sources of heat, temperature changes in the vaporizer are so slight as to not affect vaporization.

While the device is designed for a method whereby fractional volumes of a volatile agent are injected per pound of body weight per hour, the percentage of vapor delivered can easily be calculated:

1 MOL = 22.4 Liters @ STP

M = Molecular Weight of Anesthetic

A = Avogadro's Number (22.4) corrected to room temperature by application of Charles Law

$$\frac{V^1}{V^2} = \frac{T^1}{T^2}$$

D = Density of Volatile Anesthetic

$$\frac{M}{A} \text{ (In Grams)} = 1 \text{ Liter of Vapor}$$

$$\frac{\frac{M}{A}}{D} \text{ (In cc. of Liquid)} = 1 \text{ Liter Vapor}$$

$$X = \frac{1}{\frac{\frac{M}{A}}{D}} = \text{Liters of Vapor From 1 cc. Liquid}$$

Then

If Minute Volume = 8 Liters

If, for example, 1 per cent vapor is desired from vaporizer .08 (approx.) liters of vapor should be added per minute

And

$$\frac{.08}{X} = \text{cc./minute liquid to be injected}$$

Halothane

.71 cc. per minute injected	2%	at 8 liters minute volume
.35 cc. per minute	1%	
.17 cc. per minute	.5%	

Diethyl ether

6.9 cc. per minute injected	20%
3.47 cc. per minute	10%
1.73 cc. per minute	5%

Chloroform

.26 cc. per minute	1%
.52 cc. per minute	2%
.78 cc. per minute	3%

Methoxyflurane

.19 cc. per minute	½%
..38 cc. per minute	1%
.76 cc. per minute	2%
142 cc. per minute	3%

References: Morris, L. E.: New vaporizer for liquid anesthetic agents, ANESTHESIOLOGY **13**: 587, 1952; Morris, L. E., and Feldman, S. A.: Considerations in design and function of anesthetic vaporizers, ANESTHESIOLOGY **19**: 642, 1958; Fabian, L. W. *et al.*: Method for determining vapor concentrations of volatile anesthetic drugs, ANESTHESIOLOGY **19**: 51, 1958; Handbook of Chemistry. Handbook Publishers, Inc., 1952.

A Simple Apparatus for Administration of Halothane

Captain Norman R. Hillmer, Lt. Konstantine Kalandros, and Major Paul R. Hummell of Valley Forge General Hospital note that a method of efficient vaporization and introduction of halothane into a closed anesthetic circuit has posed some problems. They describe an inexpensive adaptation of a standard Heidbrink ether vaporizer for this purpose.

A polyvinyl plastic catheter (diameter 0.039 inch) is fitted over a blunted 23 gauge needle attached to a one-way stopcock and a 5-cc. syringe. The plastic catheter is passed through a small rubber or cork stopper which will fit the filling port of a Heidbrink ether vaporizer in place of the screw plug. Passage of the catheter through the stopper is accomplished by first introducing an 18 gauge needle (thin-wall) through the stopper. The catheter is threaded through the needle, and the needle is withdrawn over the tubing. The stopper is placed in the filling port of the vaporizer and the catheter is adjusted to deliver the halothane directly onto the wick in order to aid vaporization.

The vaporizer may be on either the inhalation or the exhalation side of the circuit. Preferably it should be on the exhalation side to allow dilution of the agent in the rebreathing bag. Because of this dilution on the exhalation side, the vaporizer is ordinarily left wide open. If the vaporizer is on the inhalation side of the circuit it is better to use it partially closed to avoid sudden high concentrations of the agent. (A setting near three on the scale has been found to be adequate.) In any event, the variable opening provides a good safety factor. If too much halothane is injected the vaporizer may be closed. The agent can be gradually admitted by opening the vaporizer as needed.

A more permanent apparatus as illustrated has been made by one of us (K. K.) utilizing a 10 inch length of stainless steel tubing (inside diameter approximately 0.039 inch in order to fit snugly over the blunt 23 gauge needle), and a small piece of polyvinyl or polyethylene plastic (as from a squeeze bottle) approximately $\frac{1}{16}$ inch thick. As before, the 23 gauge needle, one-way stopcock and 5-cc. syringe are utilized.

The ball and spring safety valve are removed from the standard metal screw plug of the filling port. A disc of the plastic is cut to size (approximately $\frac{5}{32}$ inch diameter) to fit into the hiatus from which the ball was removed. A small hole is punched in the center of this plastic disc and the stainless steel tubing is then fitted into place in the plug. The spring and retainer are slipped over the tubing and

A simple apparatus for closed halothane anesthesia.