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Copper Kettle Revisited

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A new vaporizer for liquid anesthetic agents. By Lucien E. Morris. ANESTHESIOLOGY 1952; 13:587–93. Reprinted with permission.

An increasing dissatisfaction with available equipment for the vaporization of liquid anesthetics led to a focused effort to design a new and improved vaporizer. Deficiencies in existing apparatus were identified as a lack of vernier control over small increments for gradually increasing the concentration of the vapor, and the lack of a steady reproducible vapor output due to the wide variation in temperature of the vaporizing liquid. Therefore a new apparatus has been designed to provide reproducible conditions for effective vaporization and vernier control over small increments in concentration of vapor offered to the patient. The important modifications for attaining these desired conditions are in the circuit design, the liquid container, and the vaporizing surface. Since there are still many occasions for which liquid anesthetics are being used as the agent of choice, it seems desirable to have available a device that provides the physician with discrete control over the vapor volumes and concentrations of these agents.

IT was unexpected but admittedly gratifying to learn that my article of more than 50 yr ago, "A New Vaporizer for Liquid Anesthetic Agents,"[1] has been designated for commentary in the current section of ANESTHESIOLOGY, "Classic Papers Revisited."

The creation of what became known as the Copper Kettle vaporizer evolved partly because of increasing dissatisfaction with existing available equipment, and partly because of a personal challenge.

In the first half of the 20th century, administration of anesthetic vapors varied from open drop techniques to use of anesthetic machines with metered flow of oxygen and anesthetic gases that could be supplemented by anesthetic vapor obtained by diverting a coarsely variable portion of the total flow of gases over or through the liquid anesthetic before being returned to the bulk of the total flow of fresh gas being offered to the patient. The sudden changes in vapor concentration led frequently to patient discomfort and slowness of induction. The usual container for the liquid anesthetic was a glass bottle, and the bubbles were usually large, therefore providing only a limited increase of surface at the gas–liquid interface. Because of the lack of an adequate external source of the heat required for vaporization, the liquid itself chilled rapidly with a consequent decrease in vapor output. Thus, the control of vapor output from these glass bottle vaporizers was a grossly imprecise "guesstimate." Generations of anesthetists learned to cope with these deficiencies. In retrospect, the desirability of obtaining control of small changes in reproducible concentrations and known volumes of vapor for addition to the respired gas mixture is very clear.

In September 1946, after active military duty including 2 yr as head of anesthesia in U.S. Army general hospitals in England and the United States, I arrived at Wisconsin General Hospital in Madison, Wisconsin, as one of the few individuals fortunate enough to experience residency training at the academic anesthesia center established by Ralph M. Waters, M.D., at the University of Wisconsin.†

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† The appointment in 1927 of Ralph M. Waters, M.D. (1883–1979) to the University of Wisconsin Faculty of Medicine as Assistant Professor of Surgery (in charge of anesthesia) was a unique and historically important event in the development of the medical specialty of anesthesiology. For the previous 80 yr, anesthesia had been a neglected area of medical education and medical practice. With this position, Dr. Waters became the first in the world full-time, salaried academic professorial appointment in anesthesiology. He then developed academic programs of medical education and research involving both medical students and graduate physicians, which immediately attracted widespread interest and international acclaim. Although often referred to as the Department of Anesthesia and frequently emulated as a model for subsequently developed medical school departments, the program at the University of Wisconsin remained as a subsection of the Department of Surgery until after Dr. Waters' retirement. It did not attain the status of a fully independent medical school department until 1952 under the leadership of Professor Sydney Orth, Ph.D., M.D.[2]

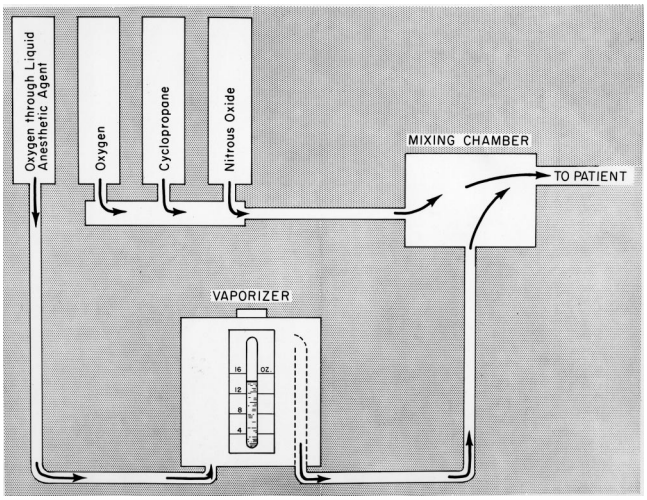

Fig. 1. Schematic diagram of circuit design showing metered flow of carrier gas through the liquid being vaporized.

In my second year, I was involved in several research projects in both laboratory and clinical anesthesia, including several aspects of the ongoing departmental research study of chloroform, which was being subjected to scrutiny as though it were a brand new agent.[3] During this time, I had worked quite closely with Dr. Waters on some of the chloroform cases. I know that at some point, I had become increasingly frustrated by the poor control over chloroform vapor and that I had vehemently expressed myself to the effect that "anyone ought to be able to make a better vaporizer than this." Several weeks later, Dr. Waters had taken a brief winter vacation in Florida during which he sent a postcard greeting back to the staff and residents in anesthesia with a single comment: "Has Morris made a new vaporizer yet?"

With this stimulus, I interrupted other projects sufficiently to seriously consider ways to potentially solve the problem. My laboratory notebook of that time contains three separate ideas, all of which were tried in the laboratory. Only the circuit change to provide a separate measured flow of carrier gas, all of which is bubbled through the vaporizer, seemed worthy of further trial and study. Oxygen was chosen as the carrier gas so that if the oxygen supply were to fail, so also would the addition of anesthetic vapor cease (fig. 1).

Two additional components were included in the design of this new vaporizer. First, to provide the heat necessary for vaporization and to prevent undue chilling of the liquid agent, a decision was made to replace the ubiquitous glass bottle of previous decades with a container made of the metal copper to hold the liquid to be vaporized. Second, the need for known, reproducible concentrations and volumes of vapor ideally requires a steady output by the vaporizer. This is approached by the relative thermostability associated with the copper container, the copper tabletop, and the sintered bronze bubbler, all of which facilitate the transfer of heat from the surrounding air to the vaporizing liquid. A constant source of saturated vapor is assured by passing the metered flow of carrier gas through sintered bronze with the resulting dispersion into a multitude of extremely small bubbles with a combined surface area to make an almost infinitely large gas–liquid interface, which in turn provides almost instant saturation. The volume of entrained vapor per unit of carrier gas depends on the pressure of saturated vapor at the observed temperature of the particular vaporizing liquid agent, each of which has its own characteristic vapor pressure curve. As an example, when a particular agent has a saturated pressure of 250 mm and the known total ambient pressure is 750 mm, then 50 ml metered carrier gas flowing through the vaporizing liquid will result in an effluent from the vaporizer of 75 ml, the 50 ml metered carrier gas plus 25 ml of that vapor. Obviously, this is a highly concentrated output, which at 33% may be up to more than 30 times an appropriate anesthetic concentration. Such a concentrated output must be added cautiously in small amounts intermittently to the respired gas mixture or, in the high-flow systems, must be properly diluted with other gases in the total flow offered to the patient.

The first manufactured apparatus to include some of the design principles of this new vaporizing system was made by the Foregger Company, New York, New York, and delivered to us at Wisconsin in the late summer of 1948. This early prototype is now at the Wood Library Museum in Park Ridge, Illinois. Although it did have the separate metered vaporizing circuit and the copper container for anesthetic liquid, it did not satisfactorily meet all of the criteria that had been worked out previously in the laboratory. However, it was possible to gain clinical experience with this apparatus, and further laboratory studies were done. Persuading the manufacturer to comply with all of the design features of this new apparatus was not easy. Finally, after numerous letters of explanation and several vigorous face-to-face discussions with Richard von Foregger, Ph.D., himself, there was a somewhat grudging agreement to include all of the design suggestions that I had made. In late 1951, I received the first satisfactory commercial model of the Copper Kettle vaporizer, which was pictured in the 1952 publication (fig. 2). This machine is now at the Guedel Memorial Anesthesia Center in San Francisco, California. Further clinical trials and laboratory studies were done with this apparatus, which resulted in several further modifications, most of which were because of safety considerations. The most notable of these were a side arm funnel for filling the liquid container, to prevent overfilling, and also a double cam valve for the positive exclusion of both the outflow and inflow of the vaporizing chamber. The control of this exclusion valve was in tandem with the emergency flush valve for oxygen, so that any possibility of either entrainment of vapor or buildup of

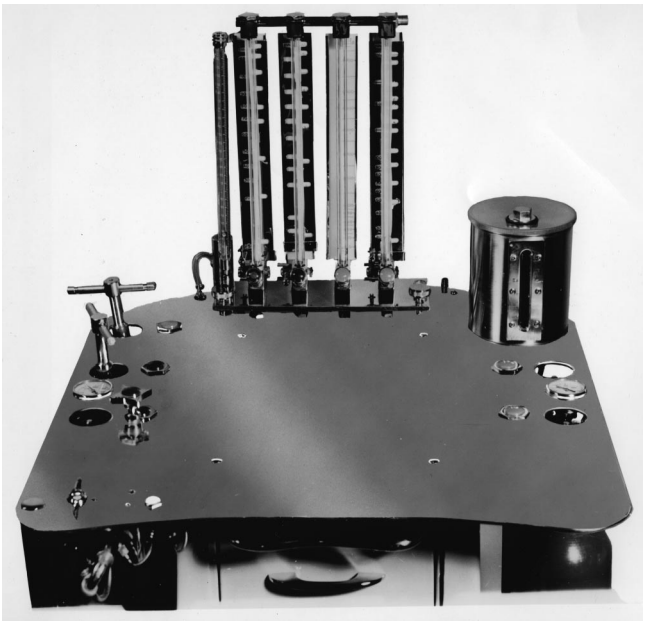

Fig. 2. Photograph of Copper Kettle, which is now at the Guedel Memorial Anesthesia Center in San Francisco, California.

pressure in the vaporizer to allow a surge after the oxygen flush would be prevented.

Although the design of this innovative vaporizer was motivated by the perceived need for better control over concentrations and volumes of chloroform vapor, it soon became apparent that this was a versatile piece of precision equipment that would be suitable for use with many other anesthetic agents that are liquid at room temperature. Indeed, it became quite clear that this vaporizer, with its vernier control over volumes and concentrations of vapor, would be excellent for the administration of diethyl ether. Because of the ability to have smooth and gradual increases in ether concentration, inductions were rapid and could be also without discomfort to the patient. In addition, it became rapidly evident that it was equally easy to overdose a patient with ether. The concept of "good old safe ether" was no longer appropriate when ether was administered by use of the Copper Kettle! It also seemed best to limit its use to the spontaneously breathing patient and to carefully adjust vapor output in accordance with patient response and the surgical needs at the moment.

Although the circuit of the Copper Kettle design was usable in all the various systems of anesthesia management, we had some early concern because of the ease of overdosage that caused us to publicly promote the use of the Copper Kettle primarily in the high-flow and semiclosed systems.

After halothane was introduced in the late 1950s, it rapidly replaced ether, and again the Copper Kettle was often the equipment of choice for its administration.

In the several years after the original publication,[1] there were additional articles presented in an effort to clarify and increase understanding of the concepts and underlying principles, which are embodied in the design of this versatile vaporizer.[4–6]

This precision tool for the administration of anesthetic vapors rapidly became popular and remained the preferred anesthesia machine in many of the U.S. teaching hospitals for many years. The Foregger Company developed several models incorporating the principles of the Copper Kettle, but after the death of Richard von Foregger, the company made some inappropriate modifications without consulting with the original designer and ultimately went out of business, so that the original Copper Kettle was no longer available for purchase in the United States.

Over the years, copies of the Copper Kettle were made in the United States, Japan, and South America as well as in the United Kingdom. However, most of these abrogated one or more of the underlying principles, which were part of the original design. In England, for instance, a so-called copy used the separate carrier gas flow but continued to use the old glass bottle. Because of this, users never gained a full appreciation of the benefits of the Copper Kettle itself. This versatile tool for administration of inhalation anesthesia with anesthetic vapors was in general use in the United States for approximately 25 yr but eventually went out of favor because of ill-advised modifications that were made by the manufacturer and because of misuse and lack of appreciation for the dangers of overdosage. Just as with a car or truck, the best safety device of any potentially harmful equipment is the knowledge and full attention of the operator!

Many years later, when I was asked to participate in a symposium on the closed-absorption techniques, I did so with the understanding that among my presentations that there would be an article on the use of the Copper Kettle in the closed-absorption system.[7]

After introduction of the Copper Kettle, there was a flurry of commercial interest in trying to provide equipment that would compete with its capabilities. These were mostly various adaptations of agent-specific direct reading percentage vaporizers, the earliest of which were often faulty and imprecise. All of these percentage scale vaporizers are intended for use only in high-flow systems, and therefore, because only a limited volume of vapor is provided by lower flows even at maximum scale setting, they tend to prevent free choice of economic low-flow and closed-absorption techniques.

In contrast to the direct reading percentage vaporizers, which tended to encourage "cookbook" administration of anesthesia, the Copper Kettle encouraged users to think in terms of patient response, partial pressures, and volume of vapor in the vaporizer output, which (when used in the closed-absorption system) leads to a clearer understanding of uptake of anesthetics in the patient.

Another factor in the change of attitude on the part of trainees in more recent years was brought about by the

movement for standards such as the linkage of nitrous oxide and oxygen, which limits the flexibility of the administrator.

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