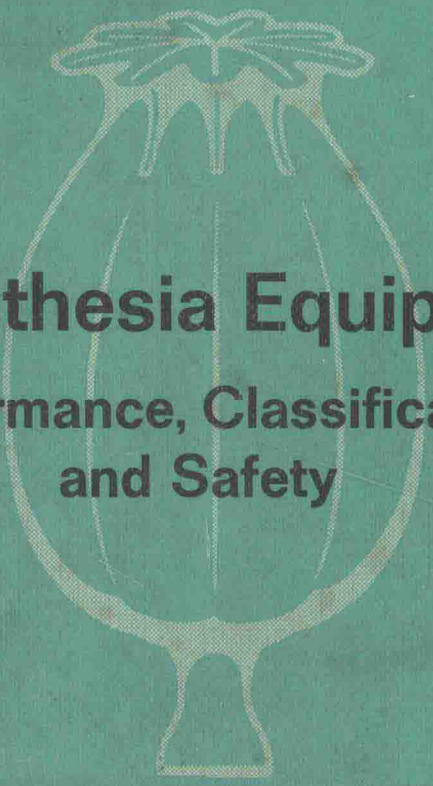
Anaesthesiology and Resuscitation
Anaesthesiologie und Wiederbelebung
Anesthésiologie et Réanimation

59

P. Schreiber



Anaesthesia Equipment

Performance, Classification and Safety

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Performance, Classification and Safety

With 155 Figures

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To my family

My wife, Ursula, who has shared the work on this manuscript and my sons, Joachim and Claus-Uwe, who have sacrificed many family weekends and vacation days for the benefit of this book.

Preface

During the recent years the basic sciences have become a major stimulant toward progress in medicine. Technique itself plays a vital role in today's medicine. With the increasing complexity of equipment, hazards related to malfunction and misuse have grown proportionally. The machine used with insufficient knowledge could become a deadly instrument.

The basic elements of the anaesthesia machine, their design, and the physical basis for their function is discussed in the monography by the engineer, Peter J. Schreiber. His knowledge is based upon fifteen years experience in the medical equipment industry in both Germany and the United States as well as his teaching activities in various medical schools.

Detailed knowledge of equipment and the related physical laws has gained increasing importance in the training of anaesthesiologists. Fundamental knowledge of the design, function, and performance of an anaesthesia machine is the key to the art of its use.

Mainz/Rhine, December 1971

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I also wish to thank the manufacturers of equipment who have provided information for this text.

Responsibility for the final form of all parts of the manuscript and for any errors that might appear rests solely upon me.

PETER SCHREIBER

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CHAPTER 1

Gas Cylinders and Medical Gases

Contents: Cylinder Marking – Safety Relief Devices – Cylinder Valve Outlets – Properties of Medical Gases – Liquefied and Non-liquefied Gases – Vapor Pressure Curves of Liquefied Gases – Rules for Safe Use, Storage and Handling of Gas Cylinders – References

Medical gases are normally stored, shipped, and supplied in metal containers called gas cylinders. The design and dimensions of gas cylinders, their valve outlets, transportation, testing, and periodic examination are subject to national standards and regulations. These national standards vary, with the exception of the Pin-Index Safety System for flush-type cylinder valves which has been adopted by a great number of countries.

Depending upon the standard regulations, the stamping on the cylinder may give the following informations: container number, symbol or other identification of the gas, identification of the manufacturer of the cylinder, owner identification, maximum filling pressure or weight, container material, wall thickness, year of first examination, date of re-examination, capacity of the cylinder, and weight of the empty cylinder. The markings may be coded, and such code designations should be available from the manufacturer.

Gas cylinders are charged and discharged through a cylinder valve which is attached to the cylinder neck by means of a tapered pipe thread. Standards require the cylinder or cylinder valve to be equipped with a safety relief device of proper discharging capacity. Such a safety relief device is intended to prevent rupture of a cylinder under certain conditions of exposure. Safety relief devices are often marked with the name of the manufacturer, the preset pressure at which the valve is set to discharge, and the flow capacity of the valve. The marking may be done through a manufacturer's code. Care should be taken in the handling and storing of compressed gas cylinders to avoid damage to the safety relief valve. Safety relief valves are routinely checked when the cylinders are refilled.

The cylinder valve outlet connections are specific to the contents of gas cylinders in order to prevent undesirable connections of the cylinders and to provide coordination between manufacturers of gas

cylinders and connecting appliances. The threaded outlets of cylinders are differentiated through internal and external as well as right-hand and left-hand threads. Within these divisions further separations are made by varying pitch and diameter of the threads.

A separate classification covers the flush outlets for medical gases which employ the Pin-Index Safety System. In many countries the gas cylinders that are directly attached to anaesthesia machines are equipped with this type of outlet. The part of an anaesthesia machine that connects the gas cylinder valve with the flush outlet is the yoke or hanger-yoke of the anaesthesia machine. The Pin-Index Safety System incorporated into this type of connection consists of a pair of pins projecting from the yoke and positioned so as to fit into matching holes in the cylinder valve. The Pin-Index Safety System itself provides for ten combinations. Those that are presently used are shown in Fig. 1.

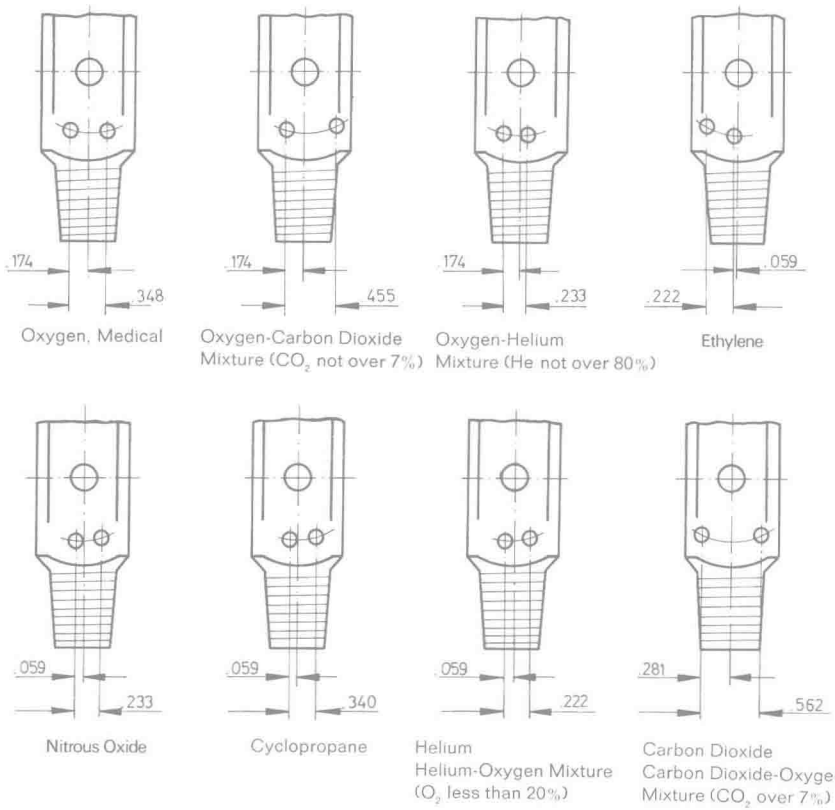

Fig. 1. Pin-Index Safety System

	Chemical formula	Molecular weight	Odor	Taste	Specific gravity kg/m³ (0° C; 760 mmHg)	Number of liters in one ounce (23° C; 760 mmHg)	Specific gravity of gas compared to air	Boiling point °C(760 mmHg)	Critical temperature °C	Specific heat $\frac{\text{kcal}}{\text{kg °C}}$ (0° C)	Heat of vaporization at boiling point $\frac{\text{kcal}}{\text{kg}}$	Combustion characteristics	Refractive index $\lambda = 546.1$ nm (760 mmHg, 0° C)	Physical state in full cylinder
Carbon dioxide	CO_2	44.01	odor-less	*c*	1.9768	15.44	1.529	− 78.5	+ 31	0.197	137	*e*	450.6	liquefied
Cyclopropane	C_3H_6	42.08	*a*	*d*	1.88	16.24	1.481	− 32.8	+125		113.9	*f*		liquefied
Ethylene	C_2H_4	28.05	*b*	*b*	1.2605	24.23	0.9749	−103.7	+ 9.9	0.35	125	*g*	729.2	liquefied
Helium	He	4.003	odor-less	taste-less	0.178	171.1	0.1380	−268.9	−268	1.25	5	*e*	34.9	non-liquefied
Nitrous oxide	N_2O	44.02	odor-less	taste-less	1.98	15.44	1.5297	− 88.5	+ 36.4	0.205	90	*h*	507.9	liquefied
Oxygen	O_2	32	odor-less	taste-less	1.4289	21.39	1.1053	−182.97	−118.4	0.218	51	*h*	272.3	non-liquefied

Fig. 2. *a* Characteristic odor resembling petroleum (benzene), *b* Slightly sweet, *c* Slightly acid, *d* Pungent, *e* Non-flammable; does not support combustion, *f* Flammable, ignition limits: In air 2.4 – 10.4 Vol.-%; in oxygen 2.48 – 60.0 Vol.-%, *g* Flammable, ignition limits: In air 2.7 – 34 Vol.-%, in oxygen 2.9 – 79.9 Vol.-%; *h* Non-flammable; supports combustion

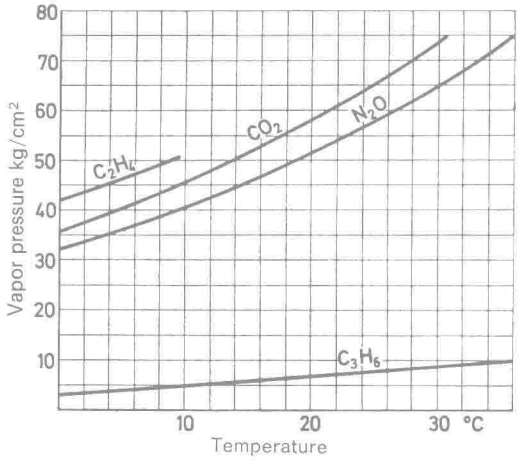

Fig. 3

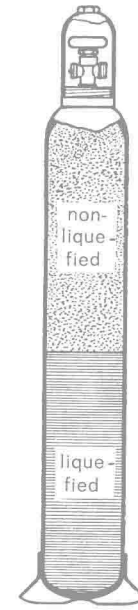

Fig. 4

Fig. 3. Vapor pressure curves of liquefied medical gases
Fig. 4. Gas cylinder filled with liquefied gas

The cylinder valves of larger size cylinders are usually provided with a protective cap in order to prevent damage to the valve during transport and storage. Most national regulations require periodic (usually five years) testing and inspection of gas cylinders.

Medical gases and their properties are listed in Fig. 2. The appropriate quality, purity, and potency of medical gases is subject to government regulation in some countries.

The pressure of a non-liquefied gas in the cylinder is determined by the amount of gas in the cylinder and by temperature. At a given temperature the approximate content of the cylinder can be calculated if the pressure in the cylinder and the capacity of the cylinder are known.

In cylinders charged with liquefied compressed gas, the pressure in the container is dependent upon the vapor pressure of the liquefied gas. Vapor pressure curves for liquefied medical gases are shown in Fig. 3. The ratio of liquefied gas to vapor in the cylinder changes with changing cylinder content (Fig. 4). The pressure remains approximately constant (at constant temperature) until all of the liquid has been exhausted. The

pressure drops in direct proportion to the content with the further withdrawal of gas. The pressure in a cylinder charged with liquefied compressed gas is not an indication of the content of the cylinder, if part of the content is in liquid phase. The quantity of gas in the cylinder can only be determined by weight.

The following rules are given for the safe use, handling, and storage of gas cylinders:

The unauthorized changing of the marking on a gas cylinder is prohibited. All marking on the cylinder must be kept readable. Full cylinders should be labeled "Full", and empty cylinders should be labeled "Empty". Flammable or poisonous contents of cylinders should be indicated by an appropriate caution label on the cylinder or its packing.

Oil or grease may combine explosively with oxygen or nitrous oxide. The contact of oil or grease with cylinders, cylinder valves, regulators, gauges, hoses, etc. must be entirely prevented. Soap and water should be used to detect gas leaks. Open flames should never be used for this purpose.

Regulators and other appliances intended for use with a specific gas should not be used with different gases. Cylinder valves should be opened fully when the cylinder is in use and should always be closed when no gas is used. The gas from a cylinder should only be used if its nature is clearly identified. Gas cylinders should not be subjected to excessive temperatures.

No repair or modifications should be performed at the safety relief valve by unauthorized persons. The cylinder should be withdrawn from service and returned to the supplier if damage to the safety relief valve has occurred or if its proper function is doubtful for some other reason. Only authorized persons are allowed to alter or repair cylinders. Persons handling compressed gases should be properly instructed in regard to hazards and regulations pertaining to compressed gases.

Protection caps for cylinder valves should be kept on cylinders when moving or storing them. If the valve outlet is provided with an additional closing nut or screw which fits the valve outlet thread, care should be taken to make sure that this part is tightly in place. Loose nuts or screws of this type may block the removal of the valve protection cap. Dropping cylinders is extremely dangerous. Large cylinders should be moved on suitable trucks.

Gas cylinders should not be filled with gases different from the intended ones. No mixing of gases should be performed in cylinders. The supplier must be notified if a foreign substance has entered the cylinder or the cylinder valve.

The storage of gas cylinders may be subject to governmental or city regulation. Persons responsible for the storage of gas cylinders should be familiar with these ordinances. The storage area for compressed gas cylinders should be specifically assigned for this purpose. The area should be well ventilated and its floor should not be below the surrounding surface. The location should be dry and cool. Oil, grease or any materials with flammable properties should not be stored in the same area.

Full and empty cylinders should be kept separate. Empty cylinders should be stored with their valves closed. Additional division of cylinders should be made on the basis of the types of gas and their fire hazards. Small cylinders may be stored in the horizontal position on properly constructed shelves. Large cylinders, if stored in an upright position, should be placed against a wall and properly chained. A cylinder should never be left in an upright position without protection. Cylinders stored in the open should be protected against the extremes of weather such as rain, ice, snow, or sunlight. Cylinders should not be stored in an environment which may cause corrosion. Dampness and the vapors of corrosive chemicals may result in rusting of cylinders and cylinder valves. Unauthorized persons should be kept out of the areas in which cylinders are stored.

In case of fire, cylinders must be removed from the endangered area immediately. Proper warnings must be given if the possibility exists that gas cylinders were left in an area endangered by fire.

Gas cylinders should not be used without suitable pressure regulators, with the exception of C_3H_6. Before the actual attachment of a pressure regulator the cylinder valve should be momentarily opened slightly in order to remove dirt or dust. During this procedure the outlet of the cylinder should be directed in a manner such that no person is endangered.

No excessive force or improper tools should be used to open or close the cylinder valve. The feed-back of foreign gases into the cylinder must be prevented with any systems to which the cylinder may be connected. Not more than one washer should be used to tighten the connection between cylinder valve and yoke. Two or more washers may eliminate the safety effect provided by the pin arrangement. The cylinder valve must be opened slowly to avoid ignition of the gas due to recompression in the regulator. The cylinder valve must be closed and the pressure in the system released before the cylinder is disconnected. The transfer of compressed gas from one cylinder to another is prohibited in some countries. Gas cylinders withdrawn from service should be permanently destroyed. They should be cut into two or more pieces.

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CHAPTER 2

Pressure and Pressure Gauges

Contents: Units of Pressure – Kinds of Pressure – Pressure Gauge Classification – References

Pressure may be defined as force acting against a given area. Basically there exist two types of units for measuring pressure. Pressure may be expressed as weight per unit area or as the height of a liquid column. The first alternative clearly adheres to the definition according to which a weight (force) acts against a certain area. In the English system the unit of area is usually the "square inch" with the pound as weight unit (pounds per square inch – psi). In the metric system, the square centimeter is the most common unit of area with the kilogram (kg) as weight unit (kilograms per square centimeter – kg/cm^2).

Units of pressure referring to the height of a liquid column do not express a direct relationship between force and area. The first measurements of pressure were performed by EVANGELISTA TORRICELLI and OTTO VAN GUERICKE. Both used tubes filled with liquids (water and mercury). In the use of a liquid column the pressure is determined by the weight of the liquid column effective on the cross-sectional area of the tube. The weight of the liquid column is dependent upon the cross-sectional area, the height of the column and the specific gravity of the liquid:

$$W = A \cdot H \cdot \mathrm{gr}\,.$$

Since pressure is the quotient of weight per area,

$$p = \frac{A \cdot H \cdot \mathrm{gr}}{A} = H \cdot \mathrm{gr}\,.$$

Hence, the area cancels out, pressure is determined from the height of a defined liquid column and the specific gravity of the liquid. The effect of temperature upon the specific gravity must be taken into consideration if a liquid column is used to measure pressure. Usually, 20° C is considered standard temperature. When pressure is expressed in terms of a liquid column, the liquid must be designated (usually water or mercury). In the English system the height may be expressed in inches or feet; in the metric system in meters, centimeters, or millimeters.