The Calibration of Anesthesia Vaporizers by Infrared Spectroscopy

RODRIGO PAREDES, M.S., ANGEL ZAPATA, CHEM. ENG.,
NELLY PALACIOS, CHEM. ENG., VICTOR TEJADA, M.S.*

An infrared spectrophotometric method is presented by which it is possible to determine the composition of gaseous mixtures of volatile anesthetics in oxygen flowing from a vaporizer by measuring the absorbance of the mixture at a suitable wavelength.

RESULTS AND DISCUSSION

In order to calibrate an anesthesia vaporizer it is necessary to be able to determine the composition of the outcoming gaseous mixture at various settings of the vaporizer dial and at certain oxygen flows.[1, 2, 3] It is well known that most organic molecules absorb in the near infrared [4] and since most known anesthetics are organic, a quantitative spectrophotometric method [5, 6] appears to be possible to determine the composition of the gaseous flow coming out of the vaporizer. Such a method was developed by us for the anesthetic methoxyflurane (Penthrane) in a Heidbrink No. 8 Anesthesia Vaporizer † and is presented as the specific example of the general method.

Beer's absorbance law: [7] $A = abc$ states that at a certain wavelength the absorbance A of a solution, when the solute is the only absorbing species, is a function of (1) the absorptivity a of the solute, (2) the pathlength of the cell b in centimeters, and (3) the concentration c expressed in moles of solute per unit volume of solution. In an anesthesia vaporizer the outcoming gaseous mixture is a flowing gaseous solution of the anesthetic (solute) in a solvent (oxygen) and as such Beer's law might be expected to hold when applied to the quantitative determination of the gaseous mixture. Experimentally the outcoming gaseous flow was allowed to sweep through a 10 cm. long infrared gas cell for a minute or so. Then the cell stopcocks were closed, the cell put on the spectrophotometer and the absorbance was recorded at the specified wavelength.‡

In the specific case of methoxyflurane as anesthetic the following abbreviations are used:

n_m = moles of methoxyflurane in gas cell,
n_t = moles of methoxyflurane plus moles of oxygen in the gas cell,
V_t = volume of the gas cell in liters,
X_m = molar fraction of methoxyflurane in the cell.

The following relationships appear:

$$c = \frac{n_m}{V_t} \qquad X_m = \frac{n_m}{n_t}$$

and assuming ideal gas behavior:

$$c = \frac{n_m P}{n_t RT} = \frac{X_m P}{RT}.$$

Substituting c in Beer's absorbance law:

$$A = \frac{abP}{RT} X_m.$$

This equation shows that at constant room temperature T, atmospheric pressure P and cell length b, the absorbance A is a function of the mole fraction X_m since the absorptivity a and the gas constant R should both be constants provided Beer's law and ideal gas behavior are followed. If these conditions apply, a plot of A versus X_m should give a straight line with slope abP/RT and intercepting the origin.

Standardization. In order to obtain a plot of A versus X_m it is necessary to know the molar fraction values X_m of standard gaseous solu-

* Chemistry Department, Universidad del Valle, Cali, Colombia.

† The vaporizer was kindly loaned to the Department of Chemistry by the Universidad del Valle University Hospital.

‡ The instrument used was a Perkin-Elmer 137 Sodium Chloride Spectrophotometer. Two 10 cm. long NaCl gas cells were used. One was filled with oxygen and placed in the reference beam, the other in the sample beam. The base line was set at approximately zero absorbance through a scan from 4 to 11 microns with both cells filled with oxygen.

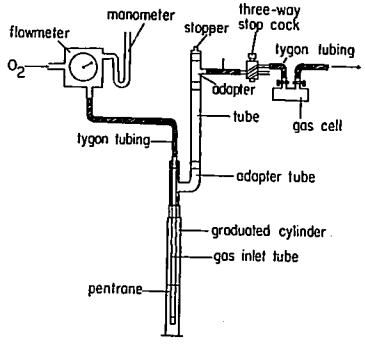

FIG. 1. Apparatus used for the standardization procedure.

tions and to record their absorbances at the specified wavelength at conditions of pressure P_1 and temperature T_1. Experimentally this was done using the equipment described in figure 1 as follows. During a measured time a certain flow of oxygen is allowed to pass through the cylinder containing the anesthetic and the outcoming enriched flow is made to sweep and fill a 10 cm. long gas cell which is then put on the spectrophotometer and the absorbance recorded at 6.87 microns.§ Several absorbance readings are taken during the process by sweeping and filling the cell at certain intervals of time and then recording the absorbance. An average absorbance value $\bar{A}$ is then obtained (table 1). The number of moles of oxygen can be calculated assuming ideal gas behavior from the flow, the time of flow and the temperature and pressure of the oxygen before passing through the cylinder containing the liquid methoxyflurane (table 1). The number of moles of methoxyflurane can be calculated from the weight of it vaporized by the flowing oxygen during the measured time (table 1). From the number of moles of oxygen and methoxyflurane the mole fraction of the flowing gaseous mixture can be calculated (table 1) and plotted versus the average absorbance $\bar{A}$ (fig. 2). Such a plot gives the standard curve shown in figure 2 which is not a straight line. Since at room temperature and atmospheric pressure ideal gas behavior is very likely to be followed for the gaseous mixture, the curvature of the plot must be due to a negative deviation of Beer's law.[7] In other words, in the slope term abP/RT, the absorptivity a is not a constant but becomes a function of the concentration of anesthetic c expressed in moles per volume of the cell in liters.

Calibration. To calibrate an anesthesia vaporizer at any set oxygen flow and dial setting two cases must be considered:

§ A three-way stopcock should be used between the vaporizer and the gas cell so that simultaneously as the cell stopcocks are closed, the gaseous flow can be made to go into the atmosphere by changing the position of the three-way stopcock (fig. 1). This operation permits maintaining the atmospheric pressure in the cell and in the vaporizer.

TABLE 1. Experimental Data Used to Determine the Standard Curve*

Determination Number	Oxygen Flow (ml./min.)	Pressure (mm.)		Temperature °K.		Time Flow (min.)	Weight of Penthrane Vaporized (g.)	Moles of Penthrane	Moles of Oxygen	Molar Fraction of Penthrane X_m	Average Absorbance $\bar{A}$ at 6.87 Microns
		Flow Meter	Room	Flow Meter	Room						
1	1,840	675	674	295	295	55.0	4.42	0.0268	3.71	0.00717	0.128
2	1,855	671	671	295	295	33.0	5.39	0.0326	2.24	0.0144	0.237
3	815	673	671	295	295	44.0	6.73	0.0407	1.31	0.0302	0.418
4	407	698	675	296	296	84.3	8.95	0.0542	1.30	0.0402	0.500

* For determinations number 1 and 2 the gas inlet tube (fig. 1) was about 1 cm. above the surface of the liquid anesthetic. For determination 2 the cylinder containing the anesthetic was submerged in a constant temperature bath at 35° C. For determinations 3 and 4 the inlet tube (fig. 1) was below the surface of the liquid anesthetic and the flowing oxygen bubbled through it. For determination 4 the gas inlet tube had a porous tip to allow the flowing oxygen to come out through the liquid anesthetic in very small bubbles.

Case One. When the atmospheric pressure P_1 and room temperature T_1 at which the vaporizer is being calibrated are the same as the temperature and pressure at which the standard curve was determined. Experimentally the outcoming gaseous mixture from the vaporizer is made to sweep and fill the gas cell § which is then put on the spectrophotometer and the absorbance recorded at the specified wavelength. Knowing the absorbance A, the composition of the gaseous mixture X_{m_1} can be read directly from the standard curve (fig. 2).

Case Two. When either or both the atmospheric pressure P_2 and the room temperature T_2 at which the vaporizer is being calibrated are different from the pressure P_1 and temperature T_1 at which the standard curve was determined. Remembering that the absorptivity a is a function of c, the concentration of the anesthetic in moles per volume of the cell in liters, let us consider the case of two identical gas cells which were filled with a gaseous mixture, the first at conditions P_1 and T_1 and the second at conditions P_2 and T_2. Furthermore, let us assume that the concentration of anesthetic c, in moles per volume of the cell in liters, is exactly the same in both cells. The absorbance will also be the same since the actual number of absorbing molecules of anesthetic in the pathlength is identical for both cells. We have then:

$$A = \frac{abP_1}{RT_1} X_{m_1} = \frac{abP_2}{RT_2} X_{m_2}$$

where

X_{m_1} = molar fraction of gaseous mixture at pressure P_1 and temperature T_1,

X_{m_2} = molar fraction of gaseous mixture at pressure P_2 and temperature T_2,

also

$$\frac{P_1 X_{m_1}}{T_1} = \frac{P_2 X_{m_2}}{T_2}$$

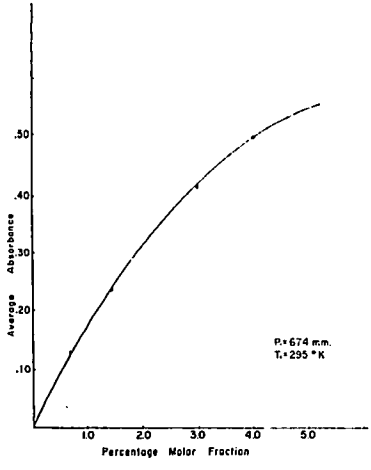

FIG. 2. Standard curve determined at indicated conditions of atmospheric pressure and room temperature.

TABLE 2. Percentage Molar Fraction* of Methoxyflurane for Each Oxygen Flow and Dial Setting of the Vaporizer at 674 mm. Atmospheric Pressure and 22° C. Room Temperature

Indicated Oxygen Flow (l./min.)	Dial Setting	Recorded Absorbance at 0.87 Microns	Percentage Molar Fraction of Penthrane*
6	10	0.275	1.73
6	9	0.275	1.73
6	8	0.260	1.62
6	7	0.232	1.42
6	5	0.107	0.61
6	4	0.055	0.31
6	3	0.013	0.07
4	10	0.300	1.92
4	9	0.280	1.77
4	8	0.290	1.84
4	7	0.261	1.62
4	6	0.150	0.88
4	5	0.099	0.56
4	4	0.034	0.19
2	10	0.345	2.29
2	9	0.330	2.17
2	8	0.340	2.25
2	7	0.285	1.81
2	6	0.110	0.63
2	5	0.010	0.06
2	4	0.054	0.30
0.5	10	0.340	2.25
0.5	9	0.360	2.43
0.5	8	0.360	2.43
0.5	7	0.232	1.42
0.5	6	0.090	0.51
0.5	4	0.038	0.21

*The percentage molar fraction is numerically equal to the percentage volumetric composition.

solving for X_{m_2}

$$X_{m_2} = X_{m_1} \frac{P_1 T_2}{P_2 T_1}.$$

Experimentally the composition of the gaseous mixture X_{m_2} flowing from the vaporizer at ambient conditions P_2 and T_2 can be obtained by filling the cell and recording the absorbance as in case one. Knowing the absorbance, X_{m_1} can be read directly from the standard curve (fig. 2), and X_{m_2} can be obtained from the equation above in which the temperature must be given in absolute degrees.

The Heidbrink vaporizer was calibrated for methoxyflurane (Penthrane) using the above described method. Determinations of the gaseous mixture compositions were performed at dial settings of 3, 4, 5, 6, 7, 8, 9 and 10 for each of the following oxygen flows: 0.5, 2, 4 and 6 liters per minute. The composition determinations at the various flows and dial settings of the vaporizer were done at atmospheric pressure of 674 mm. and room temperature of 22° C. (295° K.). The results obtained are given in table 2.

SUMMARY

A general infrared spectrophotometric method is presented by which it is possible to calibrate vaporizers for volatile anesthetics at any oxygen flow and dial setting and at any atmospheric pressure and room temperature conditions. Once a standard curve has been determined at a suitable wavelength and at ambient conditions, all that is required to find the composition of a gaseous mixture from the vaporizer is to sweep and fill an infrared gas cell and to record the absorbance at the specified wavelength. Simple calculations yield the flow composition from the absorbance, the standard curve, the atmospheric pressure and the room temperature (case one and case two).

REFERENCES

1. Wasmuth, C. E., Greig, J. H., Homi, H., Moraca, P. P., Isil, N. H., Bitte, E. M., and Hale, D. E.: Methoxyflurane: a new anesthetic agent, Cleveland Clin. Quart. 27: 174, 1960.
2. Hudon, F.: Methoxyflurane, Canad. Anaesth. Soc. J. 8: 544, 1961.
3. Power, J. D.: McGill University experiences with methoxyflurane, Canad. Anaesth. Soc. J. 8: 488, 1961.
4. Bellamy, L. J.: The Infra-Red Spectra of Complex Molecules. New York, John Wiley & Sons, Inc., 1958.
5. Meites, L., and Thomas, H. C.: Advanced Analytical Chemistry. New York, McGraw-Hill Book Company, Inc., 1958, p. 328.
6. Ewing, G. W.: Instrumental Methods of Chemical Analysis. New York, McGraw-Hill Book Company, Inc., 1960, p. 77.
7. Ewing, G. W.: Instrumental Methods of Chemical Analysis. New York, McGraw-Hill Book Company, Inc., 1960, p. 24.

GADGETS

Calibrating Device for Temperature Recording

ROBERT W. TOFT, M.S.*

A widely-used technique for monitoring body temperature is by a rectal or esophageal thermistor probe, in conjunction with a readout device such as the Tele-Thermometer (Yellow Springs Instruments). The probe, which is essentially a resistor with a high temperature coefficient of resistance, forms one arm of a Wheatstone bridge circuit; the imbalance of the bridge (which reflects the temperature of the probe) is read out on a meter calibrated to read temperature directly.

If the Tele-Thermometer is also equipped with recorder output terminals, a continuous written record of variations in temperature may be produced. In setting up a recorder for this purpose, however, it is necessary to locate

* Division of Anesthesiology, The Children's Hospital of Philadelphia.