ABSORPTION OF METHOXYFLURANE

BY CONDUCTIVE RUBBER AND

POLYETHYLENE ANESTHETIC HOSE

BY

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This thesis presents the results of an investigation into the absorption of methoxyflurane by conductive rubber and polyethylene anesthetic hose. Previous studies are reviewed and theoretical considerations governing the diffusion process are discussed.

Diffusion coefficients are calculated for commercially available hose materials using different anesthetic concentrations and oxygen flow rates.

Data obtained is compared with the results of previous investigations (primarily concerned with sorption into rubber hose) and similar results are presented for polyethylene hose.

Graphical data is used to demonstrate the effect of hose material on inspired anesthetic concentration.

The advantage of disposable conductive polyethylene hose over reusable rubber hose is shown.

APPROVAL OF THESIS

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FOR

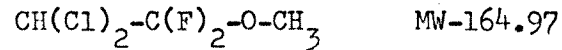NEWARK COLLEGE OF ENGINEERING

BY

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INDEX

Methoxyflurane is a halogenated hydrocarbon anesthetic with
the formula

$$CH(Cl)_2-C(F)_2-O-CH_3 \qquad MW-164.97$$

2,2-dichloro-1,1-difluoroethyl methyl ether

It is a non-flammable inhalation anesthetic used for general
anesthesia for all types of surgery.

Delivery is accomplished by contacting a mixture of nitrous
oxide and oxygen with the anesthetic in a vaporizer. The vaporized
anesthetic is carried to the patient through a circuit which, sim-
plified, consists of a breathing hose (40" to 60" long), a "Y" adapter
and a mask or endotracheal tube.

It is desirable to be able to control the uptake of anesthetic
by the patient. Much work has been done to quantify the action of
inhalation anesthetics. The concept of minimum alveolar concentration
(MAC) was developed to assist anesthesiologists in the calculation of
necessary quantities of anesthetics.

However, circuit components have been found to absorb anesthetics
rendering precise control difficult. Since desired quantities of
anesthetic are not reaching the patient, induction is prolonged.

Eger and Brandstater[8] have shown that the circuit can absorb as
much as 50% of delivered gas concentration in the early (critical)

stages of surgery. They demonstrated that, after 10 minutes at 3 liters per minute (LPM) the concentration delivered to the patient was only 62% of that entering the system. Lowe et. al.[17] discuss similar findings.

Because of this phenomenon, the manufacturer of this drug (Abbott Laboratories) recommends use of high initial concentrations and flows during the first 2 to 5 minutes of induction.

Samulksa et al[22] suggest that small quantities of anesthetic may be delivered to a patient from anesthetic circuit components after the vaporizer is turned off. Thus the patient is not getting the pure oxygen necessary for recovery and anesthesia is prolonged.

In addition, common practice has been to use a circuit for more than one patient. Since washout of absorbed anesthetic occurs over an extended period of time, it is possible for a patient to receive small quantities of the wrong anesthetic. In some cases this can precipitate complications or allergic reactions (i.e. Halothane, another anesthetic, can cause hepatitis).

In the past, the breathing hose material of choice has been reusable conductive rubber.

To date, studies have concentrated on the sorption of methoxy-flurane by this material. Anesthesiology is gradually progressing toward the use of less expensive, light weight, disposable conductive and non conductive polyethylene hose; primarily due to the concern

about cross contamination. However, even with polyethylene hose, reuse is common. More data regarding this material would be very useful in light of its growing acceptance.

It is the goal of this thesis to demonstrate using gas chromatography, the superiority of disposable polyethylene hose over reusable rubber and develop this test method as a screening tool for evaluation of new candidate materials.

In addition, it is hoped that this paper will provide the reader with a better understanding of the effect of anesthetic diffusion on the control of inspired vapor concentration. The effect of flow parameters on absorption/desorption and diffusion coefficients will also become clear.

Methoxyflurane has been chosen since this anesthetic exhibits high affinity for hose materials.

The description of common anesthetic delivery systems has been minimized since this thesis would probably be of interest only to individuals already familiar with anesthesiology.

LIST OF FIGURES

Chapter 1

LITERATURE SUMMARY

Galoon[11] using Halothane recognized that circuit components

absorb anesthetics; resulting in a decrease in inspired concentration.

Eger et al[7] developed upon this postulate (again using halothane).

In static experiments they measured uptake of anesthetic by rubber,

polyethylene, polyvinyl chloride, polyethylene therephthalate (Mylar),

Hypolon and other materials. Using a method developed by Galla and

Ottenstein[10] they determined Ostwald partition coefficients for each

material (Ostwald partition coefficient = volume of anesthetic dis-

solved in a material). Polyethylene was found to absorb less Halothane

than rubber:

Material	Partition Coef.
Rubber	121.2
Polyethylene	26.3

They also measured concentration changes in a flow circuit using

an infra red analyzer to demonstrate absorption profiles. From these

experiments they warned of potentially slowed induction and of the

effects of washout when circuits are used for more than one patient.

Galla and Ottenstein[10] and Lowe[16] used gas chromatography to detect

and quantify volatile anesthetics in blood, gases and tissues.

Eger and Brandstater[8] studied the absorption of methoxyflurane in rubber obtaining a partition coefficient of 742. Thus it can be seen that rubber has a much higher affinity for this anesthetic than for halothane. They also studied washout from an anesthetic circuit; demonstrating that significant quantities of methoxyflurane are desorbed from a previously exposed circuit. They also warned of "profound levels" of unwanted anesthetic if saturated equipment is used with another anesthetic/patient system.

Titel and Lowe[23] used gas chromatography to measure partition coefficients of a number of anesthetics in rubber. Their procedure consisted of packing columns with rubber and using anesthetic retention volume and time to calculate partition coefficient via the equation,

$$\lambda = (V_R^o - V_G^o) \, p_L/w_L \qquad (1)$$

V_R^o = retention volume of anesthetic

V_G^o = retention volume of an inert gas

p_L = density of the rubber used

w_L = weight of the rubber used

λ = partition coefficient of anesthetic on rubber

The partition coefficients obtained in this manner were similar in magnitude to those reported earlier.

In a paper for the U. S. Army Medical R & D command, Elam and Lowe[9] further studied methoxyflurane uptake by circuit components. They postulated that uptake is proportional to the square root of time thus proposing a diffusion controlled mechanism.

Lowe, Titel and Hagler[17] expanded on these findings and calculated diffusion coefficients for cyclopropane, diethyl ether, halothane and methoxyflurane in rubber. They confirmed that circuit uptake is proportional to

1 - Vapor concentration within the circuit

2 - Rubber gas partition coefficient

3 - Diffusion coefficient

4 - Square root of time

They also stated that washout cannot be accelerated by rapid flushing of the circuit since the rate is diffusion controlled. Thus, "as a consequence, as much as 300 ml of anesthetic may be routinely transferred from one case to a subsequent patient when agents are switched between cases."

Lowe[14] alludes to the fact that use of polyethylene hose can significantly reduce anesthetic absorption/desorption effects. However, no comparative data has yet been presented.

Chapter 2

EXPERIMENTAL

The absorption apparatus used is shown in figure no. 1. It consists of a Foregger Pentomatic methoxyflurane vaporizer calibrated from zero to 2.5% (figure no. 2 shows the manufacturer's predicted output vs flow data) driven by medical grade oxygen, a flow circuit with sampling ports up and down stream of the hose being tested and a vacuum pump to draw gas samples through a gas sample valve (figure no. 3) for injection into a Varian model 1520 gas chromatograph. High purity helium (70 - 80 psig) was used as a carrier gas for the chromatograph's thermal conductivity detector at a flow rate of 25 - 30 cc/min.

The sample column was a 10' x ¼" stainless steel tube containing 10% US 98 on a 70/80 mesh Varaport 30 support. This column provided excellent separation between the oxygen and the methoxyflurane.

The blank (control) column was also a 10' x ¼" stainless tube containing molecular sieve 5A (60/80 mesh).

Both columns were maintained at a temperature of between 95 and 105°F. The detector temperature and current were 120-130°F and 149-151 DC miliamperes respectively.
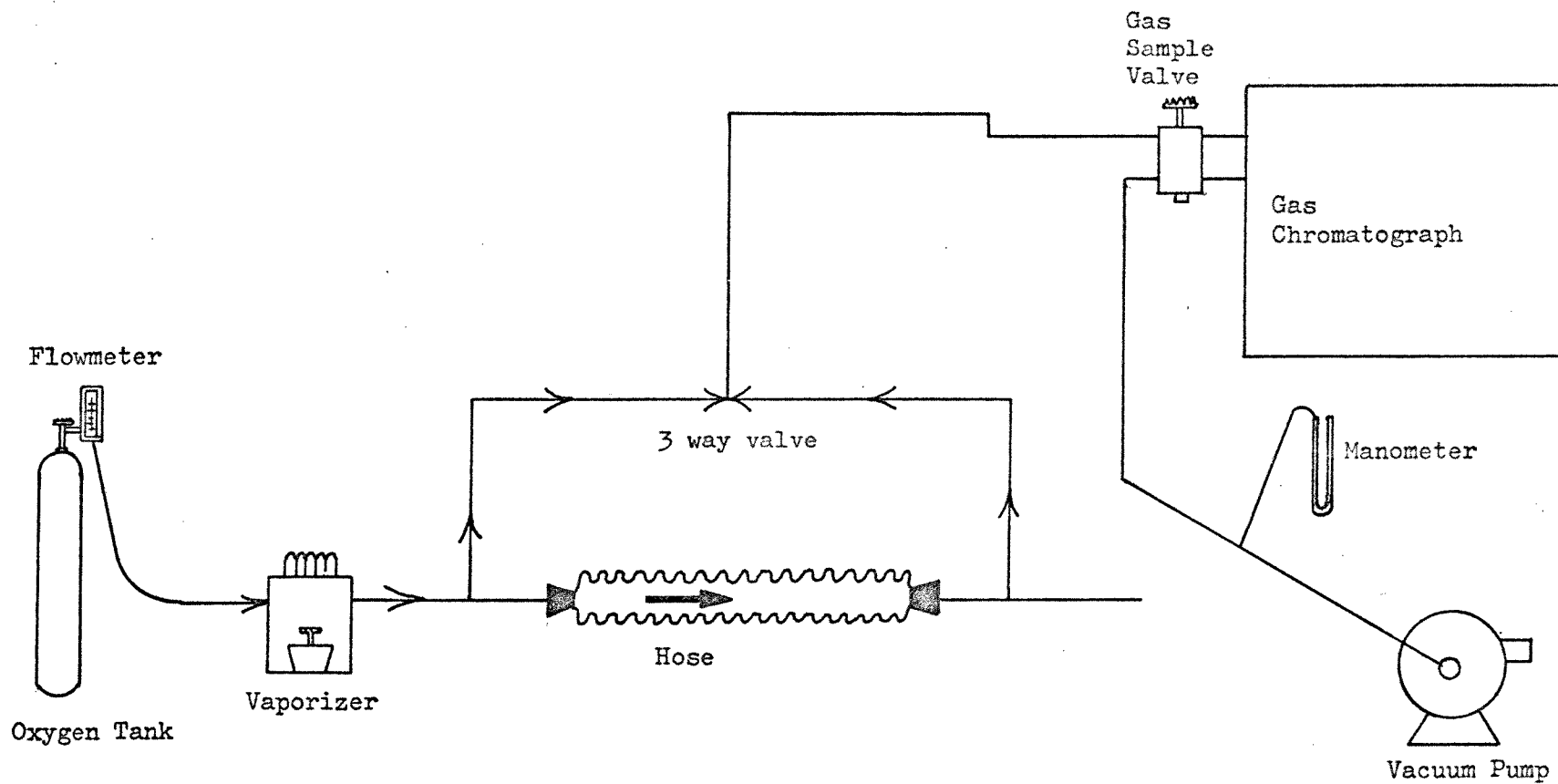
Gas
Sample
Valve

Gas
Chromatograph

Flowmeter

3 way valve

Manometer

Hose

Vaporizer

Oxygen Tank

Vacuum Pump

FIGURE NO. 1 DIFFUSION APPARATUS

FIGURE NO. 2

MAXIMUM DIAL POSITION — PENTOMATIC

When the control dial is turned to the "MAX." position, *all* of the gas flow is passed through the wick chamber. It is obvious from inspecting the temperature versus percent concentration graph that there is no effective temperature compensation when operating with the dial in the "MAX." position. In this condition, the output concentration is nearly identical with that of a Copper Kettle when no diluting gases are flowing. The percentage concentration in the "MAX." dial position is, assuming saturation is obtained, a function of the vapor pressure of Methoxyflurane, which is in turn a function of the vaporizer temperature which is affected by heat loss due to vaporization. The theoretical maximum percentage concentrations for Methoxyflurane are illustrated in the following table:

Vaporizer Temperature °C	20	25	30	35
Vaporizer Temperature °F	68	77	86	95
Vapor Pressure Penthrane mm/Hg.	23.0	30.5	39.5	50.5
Max. Concentration % Vol.	3.0	4.0	5.2	6.6

1. Vapor pressure of Penthrane — Abbott Laboratories
2. Calculated in accordance with:

$$\text{Max. \% Penthrane**} = \frac{\text{Vapor Pressure}}{760} \times 100\%$$

(S.L. Atmospheric Pressure = 760 mm/Hg.

In practice, however, the maximum obtainable concentration percentage would be somewhat less than the above due to heat losses caused by vaporization.
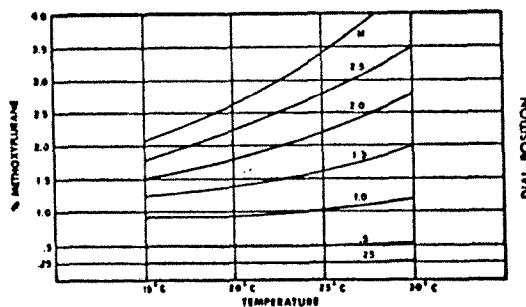
Percent Methoxyflurane versus temperature at flow rate of 4 L/M.
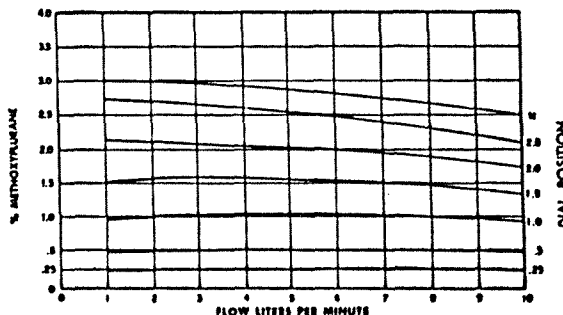
Percent Methoxyflurane versus flow; readings taken at room temperature (70°F) after successive 4 minute runs at each flow for each dial setting.

FIGURE NO. 3 GAS SAMPLE VALVE

Normal Position
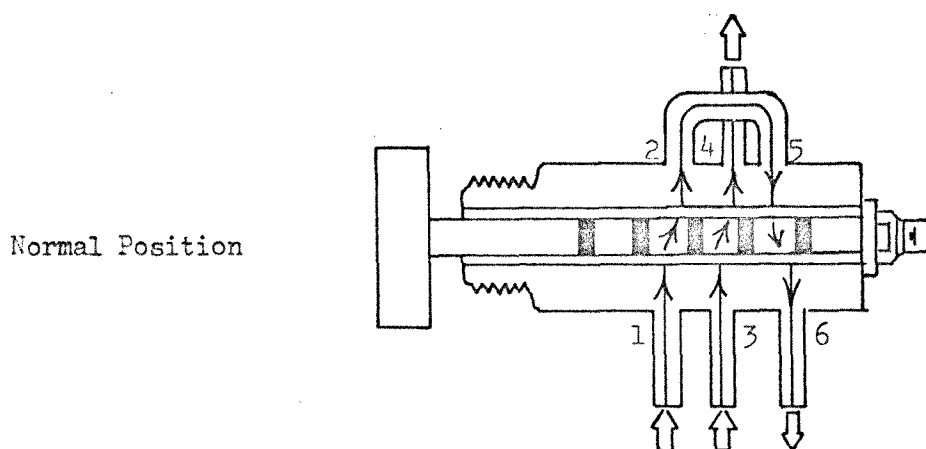
Valve Ports

1 - Sample Inlet   4 - Output to GC

2 - Sample Loop   5 - Sample Loop

3 - Carrier Gas Input   6 - To Vacuum

Inject Position
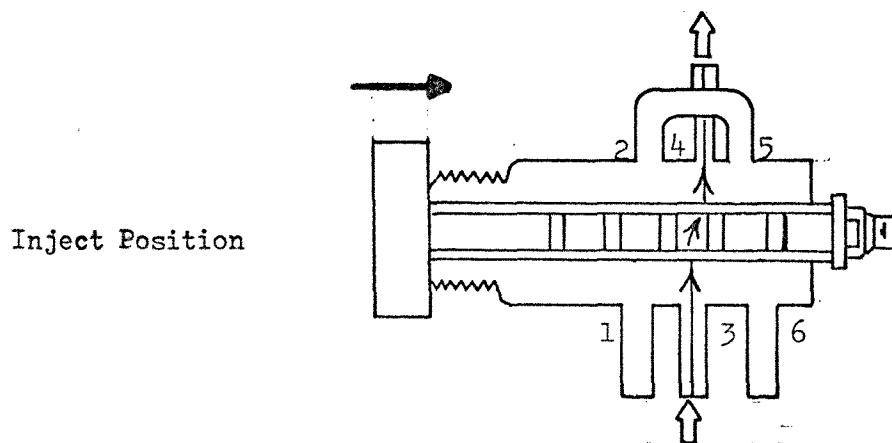
When plunger is pushed sample chamber becomes
carrier gas chamber and sample is washed into
the GC

A chart speed of ½ inch per minute was used.

Anesthetic samples were taken at intervals of 5, 15, 30, 60, and 120 minutes from the downstream tap. Use of a three way valve permitted upstream sampling at convenient intervals during each run.

Hose samples were weighed before and during each run using an Ohaus Harvard tripbeam balance.

At least 2 runs were made at each condition.

The following anesthetic hoses were used in the study (all were conductive carbon filled):

Polyethylene (disposable - sold for single use)

        1-Bard-Parker (B) div. of Becton-Dickinson and Co.;

            Rutherford, N. J.

        2-Ohio Medical Prod. (O) div. Air Reduction Co.;

            Madison, Wisconsin

Rubber (reusable - sold for multiple use)

        1-Ohio Medical Prod. (O) div. Air Reduction Co.;

            Madison, Wisconsin

        2-Foregger Co., Inc. (F) div. Air Products Corp.;

            Smithtown, L. I.

Rubber (disposable/synthetic - sold for single use)

        1-Dupaco Inc. (D) San Marcos, Cal.

Table no. 1 presents known features of each hose. All were purchased from a commercial supplier (Inhalation Therapy Inc.; Clifton, N. J.).

Table #1 - Hose Comparison

Hose Mat'l	Manuf.	Code	Avg. Lgth. (in)	Avg. Wt. (g)	Calc. Surf.* Area (cm^2)	Volume** (cc)	(g/cc)
Polyethylene	Ohio	PO	31	44	1032	312	1.21
	Bard-Parker	PB	40	66	1480	290	1.14
Rubber	Ohio	RO	36	210	1325	485	1.04
	Foregger	RF	36	200	1480	425	1.35
	Dupaco	RD	36	80	974	370	1.19

*Surface area was calculated by the following method

1-Fill a section of hose with low melting alloy metal.

2-Measure cross section on a 10:1 comparator (root and tip diameter, surface length per corrugation and axial length per corrugation.

3-Calculate surface area

$$A = (\text{Hose Lgth./Axial Lgth.}) \times \text{Surf. Lgth.} \times \frac{RD + TD}{2} \times \pi$$

RD - Root. Dia.

TD - Tip Dia.

**Volume was obtained by filling the hose with water (under water to eliminate the expansion due to water) and measuring volume collected in a graduated cylinder.

Note: As a matter of comparison, Lowe et al.[17] report area obtained for rubber hose (31" long) by pressing strips of aluminum foil to conform to corrugations of 1440 cm^2 and a volume of 500 cc.

Atmospheric conditions were maintained as close to $70^{\circ}F$ as possible by use of a commercial room thermostat.

Gas flows (Oxygen) of 2 and 5 LPM were controlled by a Puritan Bennett Flow Meter Regulator. The rotameter flow meter was pressure compensated to minimize the effect of back pressure.

Graphs were calculated and plotted using a graphical interactive computer system. The plots presented in this thesis were generated on a Tectronix 4012 terminal coupled to a Univac 1106 computer.

Chapter 3

GAS CHROMATOGRAPHY

Gas chromatography provides a simple method for determination
of methoxyflurane concentration changes due to absorption by circuit
components. A gas sample trapped in the gas sample valve (figure no. 3)
is washed into the column by helium carrier gas.

As the sample (in this case containing oxygen and anesthetic)
passes through the column its components are separated in relation to
differences in absorption or solubility on the packing. As each
component elutes from the column, it presents a gaussian distribution.
Figure no. 4 depicts the type of curve obtained in this study. The
first peak is oxygen followed by a much smaller peak for the anesthetic.

A thermal conductivity detector was used for this study. Here
the conductivity change attributable to the sample component in the
carrier gas is compared with pure carrier gas using a wheatstone
bridge circuit. Other methods of detection which could have been used
are:

    1-Flame ionization-This method is more sensitive and could permit

        detection of smaller concentrations of anesthetic. In addition,

        this detector does not detect oxygen; a feature which might

        permit more rapid sampling. Although the gas chromatograph

FIGURE NO. 4 TYPICAL GAS CHROMATOGRAPHIC CURVE

Oxygen

METHOXYFLURANE (MOF)

h

h/2

w
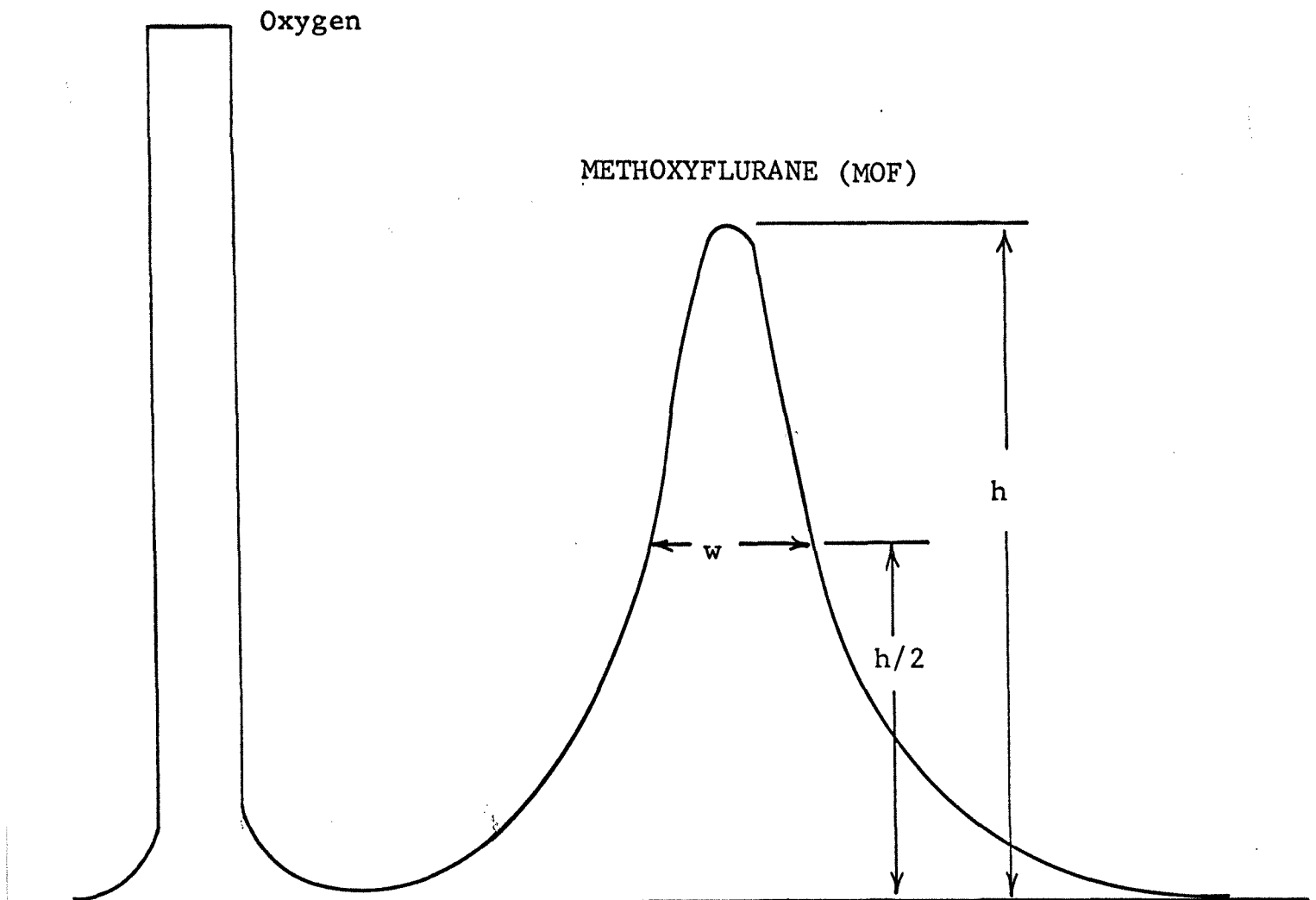
Peak Area = h X w

h = curve height

w = width of curve at half peak height

used for this thesis contained a flame ionization detector it
was not functional.

2-Electron capture-This method depends on the sample's ability to
capture electrons. Most saturated hydrocarbons do not have
sufficient affinity for electrons. However, halogenated hydro-
carbons (i.e. anesthetics) possess high affinities.

Although peak height is sometimes used as a measure of concentra-
tion, the area under the peak is more accurate. Figure no. 4 depicts
the method used for area calculation. (Peak height multiplied by width
at half height).

In this experiment, the area of the unabsorbed gas stream (taken
from the upstream sample tap) was compared with areas for samples
taken downstream of the hose to obtain comparative effluent concentra-
tions.

Chapter 4

DIFFUSION THEORY

Diffusion is the transfer of matter from one portion of a system to another by random molecular motion. Although no one molecule takes exactly the same path as any other, the cumulative vector is in one preferred direction.

Fick developed quantitive relationships for the diffusion process based on those existing for conductive heat transfer. Fick's first law of diffusion is

$$F = -D(dC/dx) \qquad (2)$$

F = diffusion rate per unit area

dC/dx = concentration gradient normal to the surface

        through which diffusion is taking place

x = thickness of the specimen

D = diffusion coefficient

The negative sign results from the fact that diffusion takes place from areas of high to those of low concentration.

D has the dimensions of length^{2}X time $^{-1}$ (i.e. in^2/sec).

Based on equation no. 2 Crank[5] derives the fundamental differential equation of diffusion. Assuming that D is a function of concentration,

as in the case of an organic vapor diffusing into a polymer, he obtains

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x} (D \frac{\partial c}{\partial x}) + \frac{\partial}{\partial y} (D \frac{\partial c}{\partial y}) + \frac{\partial}{\partial z} (D \frac{\partial c}{\partial z}) \tag{3}$$

t = time

Equation no. 3 is referred to as Fick's second law of diffusion. If the experimental constraints preclude diffusion in all but one direction, equation no. 3 reduces to

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x} (D \frac{\partial c}{\partial x}) \tag{4}$$

For radial diffusion in a cylinder where $x = r \cos \Theta$

$$\frac{\partial c}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} (Dr \frac{\partial c}{\partial r}) \tag{5}$$

For a hollow cylinder Crank shows that diffusion is similar to that for a plane sheet. A plot of M_t/M_∞ versus $\left[Dt/ (b-a)^2 \right]^{\frac{1}{2}}$ for different values of b/a from Crank is shown in figure no. 5.

M_t = Weight gain at time t

M_∞ = theoretical weight gain at infinite time

a & b = inner and outer radii of the cylinder

From this it can be seen that, as b/a approaches 1 (a plane sheet), the plots can be considered equivalent. Thus relationships developed for use in plane sheet diffusion can be employed.

Lowe et al[17] proposed a simplified relationship by which they compared diffusion coefficients of a number of anesthetics in rubber. Assuming that D is constant and related to Ostwald partition coefficient (λ)
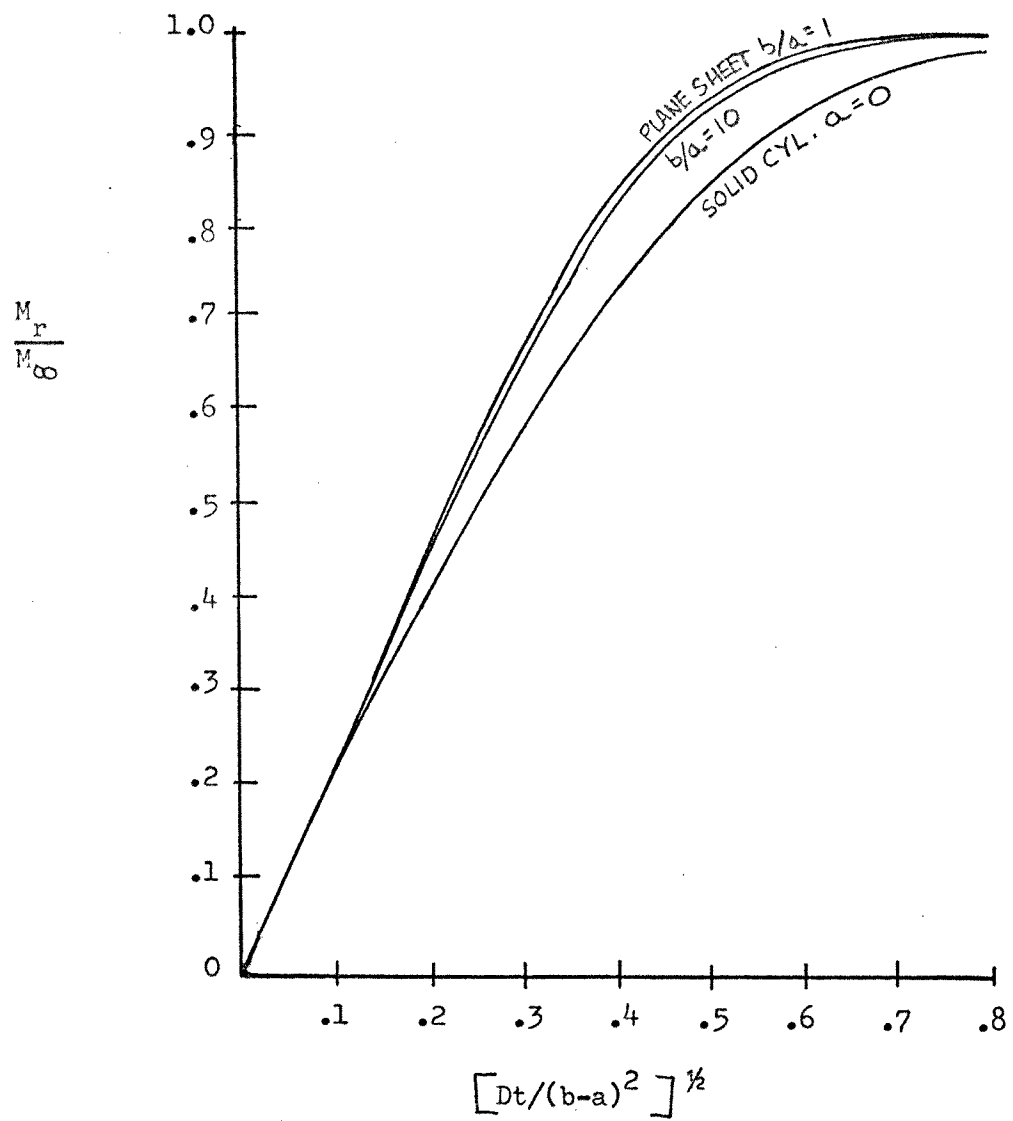
FIGURE NO. 5

UPTAKE CURVES FOR CYLINDER + PLANE SHEET

$$D = D^* \lambda$$

equation no. 2 becomes

$$\frac{d\,C}{d\,t} = -D^* \, \lambda \quad A(dC/dx) \tag{6}$$

A = cross sectional area

If vapor concentration (C_o) is maintained constant, equation no. 6 results in the relationship

$$C_t = C_o \,(1\text{-}2\sqrt{\pi}\,) \int_0^y \quad e^{-y^2} dy \tag{7}$$

where $y = x/\,(2\,\sqrt{D^*t})$

This equation can be integrated to obtain the quantity of anesthetic absorbed (Q) in time (t).

$$Q = C_o \, A \, \lambda \quad (D^*/\pi\,)^{\frac{1}{2}} t^{\frac{1}{2}} \tag{8}$$

The rate of uptake then becomes by differentiation

$$dQ/dt = \tfrac{1}{2}C_o A \lambda \,(D^*/\pi\,)^{\frac{1}{2}}/t^{\frac{1}{2}} \tag{9}$$

Equations 8 and 9 show that plots of Q versus $t^{\frac{1}{2}}$ and dQ/dt versus $(1/t)^{\frac{1}{2}}$ should be straight lines with slopes equal to $C_o A \lambda \,(D^*/\pi\,)^{\frac{1}{2}}$ and $\tfrac{1}{2}C_o A \lambda \,(D^*/\pi\,)^{\frac{1}{2}}$ respectively.

As mentioned, this simplified method assumes a constant diffusion coefficient with changing concentration. If this is not the case, a family of lines differing by parameter C_o will be obtained.

Park[20] derived a method to treat this situation. As presented in Crank and Park[4] this method proceeds as follows :

1 - Obtain a $\overline{D}^*$ for each concentration curve.

2 - Plot $\overline{D}^*C$ versus concentration and extrapolate to

zero concentration to obtain D_o^*.

3 - Obtain correction factors (I) for each $\overline{D}^*/D_o^*$

from figure no. 6

4 - Plot $\log_{10}$ I versus C .

5 - Calculate D^* from the slope where

$$\text{slope} = \frac{d\ I}{dC} = 2.3031\ \frac{d\log_{10}\ I}{d\ C} \tag{10}$$

The hose materials used in this study are carbon filled to increase conductivity. Thus the system is one of diffusion of an organic vapor in a heterogeneous medium. Due to the active nature of carbon black, adsorption and increased porosity can become important if the particles are not wholly wetted by the polymer[4]. The effect of this factor could not be fully investigated due to the lack of sufficient information regarding hose material and carbon loading.

The following is a brief discussion of other methods commonly used to obtain diffusion coefficients in gas/polymer systems.

1-Time Lag: As first developed by Barrier[3] this method consists of plotting the amount of diffusant passing through a sheet of material as a function of time. There is an initial interval before steady state is reached. If the steady state portion of the curve is extrapolated to zero uptake, the X axis intercept can be related to the diffusion coefficient by

FIGURE NO. 6

THE D VS I/C_o RELATIONSHIP

REF: PARK[20]
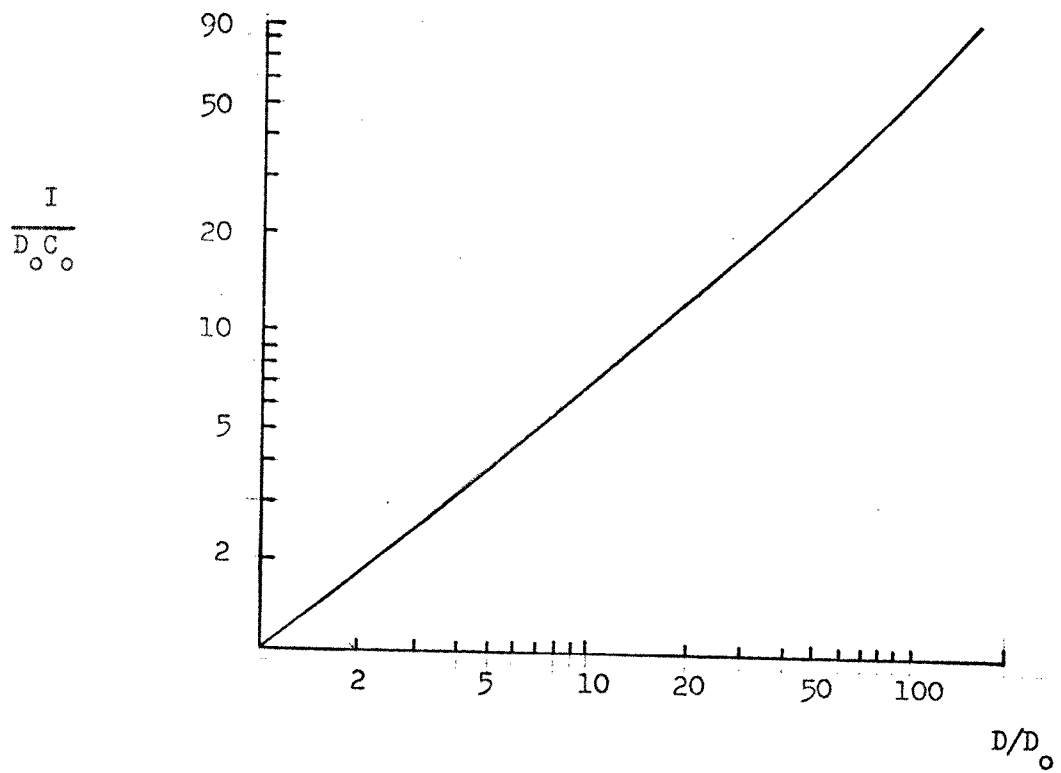
$$L = 1^2/6D$$

L = Intercept along the X axis

1 = thickness

2-Half time of non steady state curve:

The graph of M_t/M_∞ as a function of $(t/1^2)^{1/2}$ is linear to as much as M_t/M_∞ of 0.5. The value of $(t/1^2)$ for which M_t/M_∞ = ½ is related to the diffusion coefficient by[4]

$$D = 0.04919/ (t/1^2)_{1/2}$$

$(t/1^2)_{1/2}$ is the value of $t/1^2$ at which M_t/M_∞ = ½

Since availability of anesthetic did not permit runs long enough to achieve infinite absorption, the latter method could not be tested.

In the initial stages of anesthetic administration, the concentration leaving the hose is related to that entering the hose by the following relationship[14]

$$C_{out} = C_{in} (1-e^{-(\text{flow X time/volume})}) \qquad (11)$$

This relationship is referred to as the wash in process.

Thus, the inspired concentration is further reduced during the wash in period.

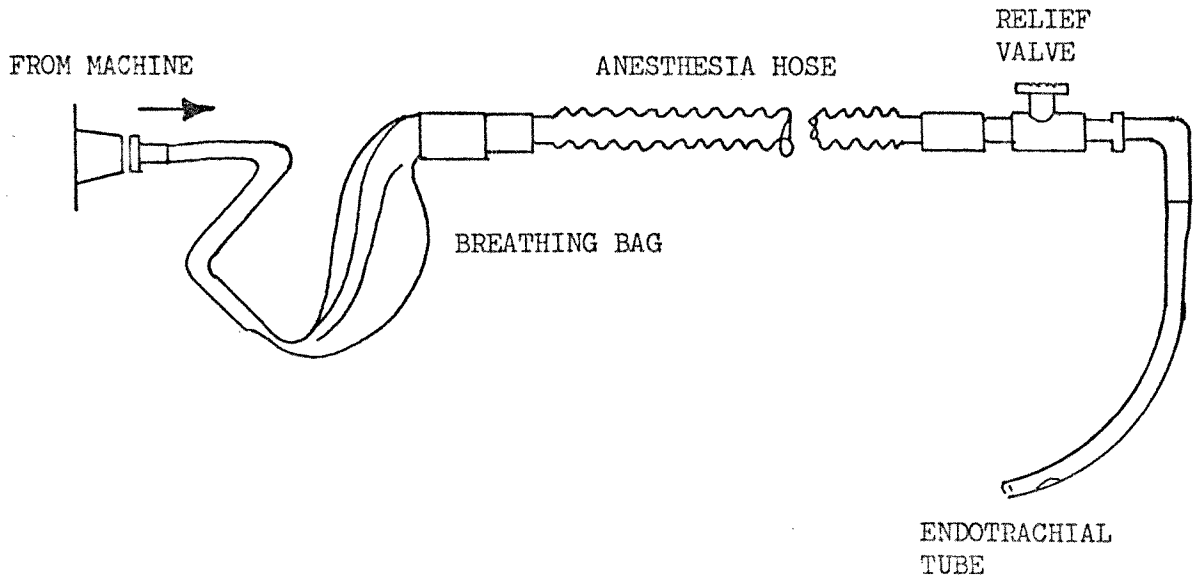Chapter 5

METHOXYFLURANE ADMINISTRATION

As with other general anesthetic agents, methoxyflurane is
administered only be adequately trained individuals. Therefore,
this section will serve as a brief discussion of commonly used methods
of administration for orientation of the layman reader.

Methoxyflurane is an inhalation anesthetic usually vaporized
from the liquid state by an oxygen/nitrous oxide carrier gas passing
through a vaporizer. Many different types of vaporizers are used.
The simplist is an open screen mask over which a drop of anesthetic is
poured. The patient breathes in carrying the vapor into his respiratory
tract. The Ohio Heidbrink No. 8 Vaporizer, the McKesson Ether Vaporizer
No. 965-A, the Pentec Vaporizer, the Foregger Copper Kettle, the Ohio
Verni-Trol Vaporizer, the Foregger Pentomatic Vaporizer (Figure no. 8
used in this study) and the Boyle Ether Vaporizer are the commonly used
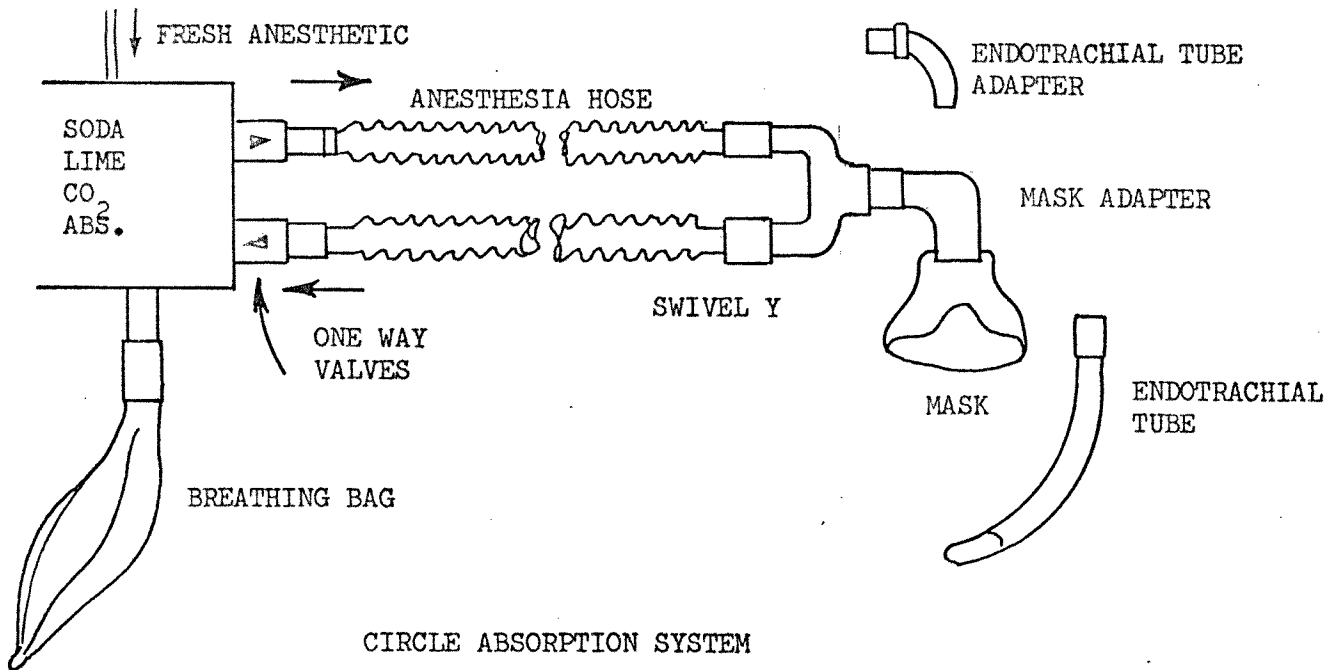units today.

Figure no.7 depicts two common patient circuit configurations.
Not shown are the vaporizer and carrier gas flow meters for concentra-
tion control which are common to both systems.
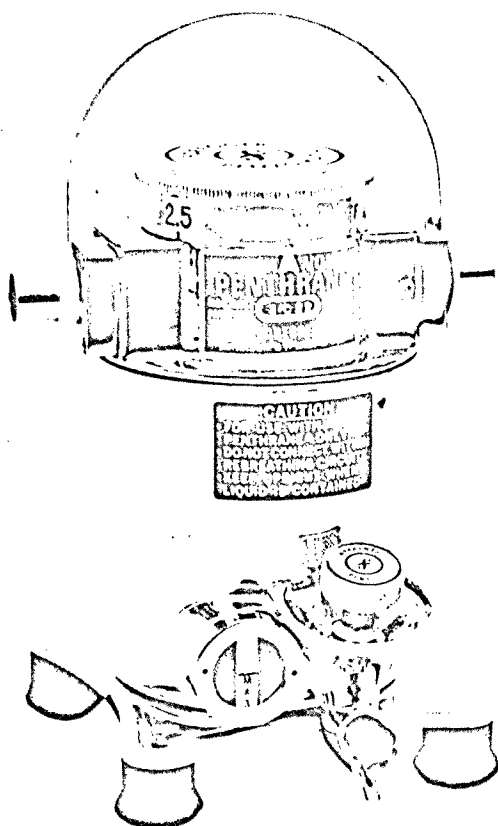
1-The semi-closed system:

FIGURE NO. 7 ANESTHESIA CIRCUIT LAYOUTS

FROM MACHINE ANESTHESIA HOSE

RELIEF VALVE

BREATHING BAG

ENDOTRACHIAL TUBE

SEMI-CLOSED OR NON-REBREATHING SYSTEM

FRESH ANESTHETIC

SODA LIME CO_2 ABS.

ANESTHESIA HOSE

ENDOTRACHIAL TUBE ADAPTER

MASK ADAPTER

ONE WAY VALVES

SWIVEL Y

MASK

ENDOTRACHIAL TUBE

BREATHING BAG

CIRCLE ABSORPTION SYSTEM

DRV-2   NO. 7-956-014
(Base Plate Optional)

The PENTOMATIC is a fresh gas impregnation type Methoxyflurane Vaporizer which is temperature compensated; flow compensated and back-pressure compensated, intended for use outside of the patient breathing circuit. It is designed to fill the need for a full range Methoxyflurane Vaporizer with accurate one-knob control. Temperature compensation is automatic over the lower percentage concentrations normally used for maintenance of anesthesia. In addition, the PENTOMATIC calibration permits concentrations up to the maximum obtainable by diversion of the entire total flow through the vaporizing chamber. The PENTOMATIC Vaporizer is accurately calibrated to meet the specified performance curves for gas flows ranging from 0.5 to 10 liters per minute, and over a temperature range of 15° to 30°C. Output concentration of the PENTOMATIC is undisturbed by pressure pulsations at the output line which result from manual assisting or use of a respirator.
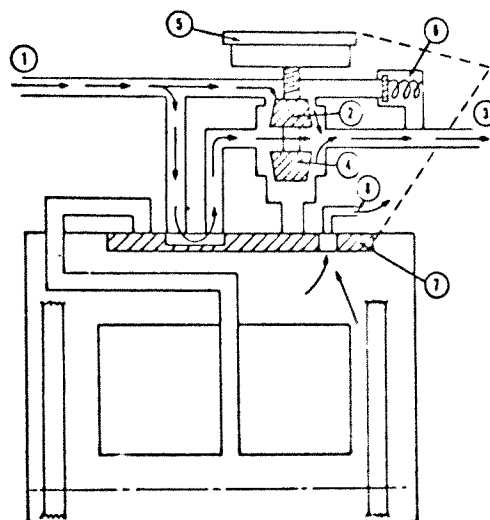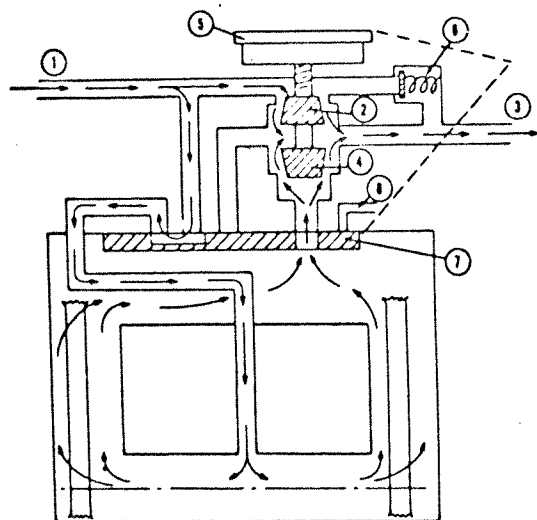
ON POSITION
Gas flow enters inlet (1) and is split into two streams. One stream passes through the upper section of the control valve (2) to the outlet (3). The second stream passes through the wick chamber and then through the lower section of the control valve (4) to the outlet. The control valve sections (2) and (4) move as a unit up or down as the control knob (5) is rotated to adjust the concentration %. Temperature compensation is accomplished by expansion and contraction of the lower section of the control valve (4). The relief valve (6) limits the inlet gas pressure in the event that abnormally high flows are applied.

OFF POSITION
The isolation valve (7) is moved through linkage to the control knob (5) so that the gas inlet and outlet from the wick chamber are closed off, a by-pass part is opened offering low resistance to the passage of gas and the wick chamber is vented to atmosphere (8).

Here, gases pass through a breathing or reservoir bag (used to ventilate the patient, to act as a means to sense lung tone and to act as a sink to prevent pressure build up and as a reservoir from which the patient breathes) and a flexible corrugated hose to the patient. In this system there is no rebreathing of expired atmospheres. Flow rates therefore equal inspired volumes.

2-Circle absorption system or closed system

This system is also known as the carbon dioxide absorption system. It is an efficient method for economizing on anesthetic usage. Here, exhaled gases are recirculated through a soda lime absorber which removes carbon dioxide. Valves control flow so that it goes only in one direction-from patient through one hose, to the expiratory valve, into the soda lime, into the breathing bag, through the inspiratory valve and thus through the other hose back to the patient. Anesthetic losses are made up by injection of a small quantity of fresh anesthetic/oxygen mixture.

In both systems, anesthetic uptake by circuit components has been found to reduce inspired concentrations. In the closed system, the inspiratory and expiratory limbs of the anesthetic circuit are exposed to different concentrations of anesthetic and uptake must be calculated separately for each[17].

Chapter 6

PROPERTIES OF METHOXYFLURANE

Boiling Point (@760mm Hg) : 104.65° C

Freezing Point : -35°C

Specific Gravity (@25°C) : Liquid - 1.42 g/cc

Vapor - 0.0068 g/cc

Maximum Vapor Concentration (@23°C) : 3.5%

Latent Heat of Vaporization : 49 cal/gram

Rubber/Gas Partition Coefficient : 630 cc vapor/cc rubber 13,17

742 cc vapor/cc rubber 11

Chapter 7

ABSORPTION/DESORPTION

The data obtained from gas chromatographic analysis of hose effluents is depicted in figures 9 through 16. These curves simulate anesthetic uptake over a two hour induction period followed by desorption into pure oxygen. All data was generated at two liters per minute. Two concentrations, 1% and 2%, were used.

It can be seen that the profiles take the same shape regardless of hose material. The magnitude of the anesthetic absorption varies with circuit material and anesthetic concentration. The same is true for the desorption profiles. Increasing the flow rate decreases contact time and thus minimizes the effect of absorption on inspired concentration. Likewise, increasing the flow rate of pure oxygen results in lower inspired concentrations during the desorption period.

Figures 17 through 25 depict the individual saturation curves for the materials tested. Figures 26 and 27 are composits comparing absorption of all hose materials at 2% and 1% concentrations respectively.

Wash in curves based on equation 11 were calculated for the 1 and 2 LPM flow using volumetric data presented in table 1. This was found to be of megligible significance since hose volumes were less than 50% of flow rate.

Hose uptake due to absorption can prevent the patient from receiving the anesthetic concentration necessary for rapid induction. Figures 26 and 27 show that conductive polyethylene hose absorbs significantly less anesthetic than conductive rubber hose. It can also be seen that different rubber materials absorb at different rates. Thus the Ohio hose was found to absorb substantially more methoxyflurane that the Foregger and Dupaco hoses. The trend seems to be a function of rubber density. At 2 LPM and 2% concentration the effluent concentration after two hours was:

	% of inlet Concentration	Density (g/cc)
Ohio Rubber	68	1.02
Foregger Rubber	90	1.35
Dupaco Rubber	84	1.19
Bard-Parker Polyeth.	98	1.14
Ohio Polyethylene	96	1.21

The desorption curves for each hose material are presented in figures 28 through 35 with composits in figures 36 and 37. Here again, the differences form similar trends. After 30 minutes with pure oxygen (2 LPM), the patient is still receiving measurable anesthetic concentrations. After two hours saturation with 2% methoxy-flurane the patient receives the following concentration during the "lightening" period:

	% of Initial Concentration (after 30 minutes)
Ohio Rubber	11
Foregger Rubber	7
Dupaco Rubber	9
Bard-Parker Polyethylene	4.5

This confirms observations reported in the literature. At low oxygen flow rates, washout can prolong anesthesia. The immediate effect can be minimized by increasing flow rate. However, diffusion can result in significant buildups of anesthetic in reused circuits which are left dormant for periods of time up to 10 hours.

Eger and Brandstater performed more extensive desorption experiments which demonstrated a similar trend. They also, showed that, with constant oxygen flow for up to 500 minutes, residual anesthetic could be detected.

Many anesthesiologists have expressed the concern that patients sensitive to certain anesthetics can be seriously affected due to washout from reused circuit components.

It is the author's recommendation that disposable conductive polyethylene be substituted for reusable rubber wherever possible. Besides the fact that use of disposable polyethylene hose significantly reduces induction time and minimizes washout effects, changing circuits after each operation can minimize the possibility of cross infection between patients.

The use of conductive anesthesia components has in the past been necessitated by the use of flamable (explosive) anesthetics such as ether and cyclopropane. The purpose was to prevent spark generation caused by static electricity build up. Many hospitals are trending away from these anesthetics due to their inherent dangers. Methoxyflurane and its sister anesthetics (Halothane and Ethrane) are non-flamable and do not require the use of conductive operation room equipment.

Non-conductive polyethylene has an insignificant absorption/desorption profile and should be chosen over conductive hose wherever possible. Control of inspired concentrations will be improved, lightening will be expedited and cross anesthetic polution will be minimized.

FIGURE NO. 9

POLYETHYLENE (BARD-PARKER) 2% 2LPM
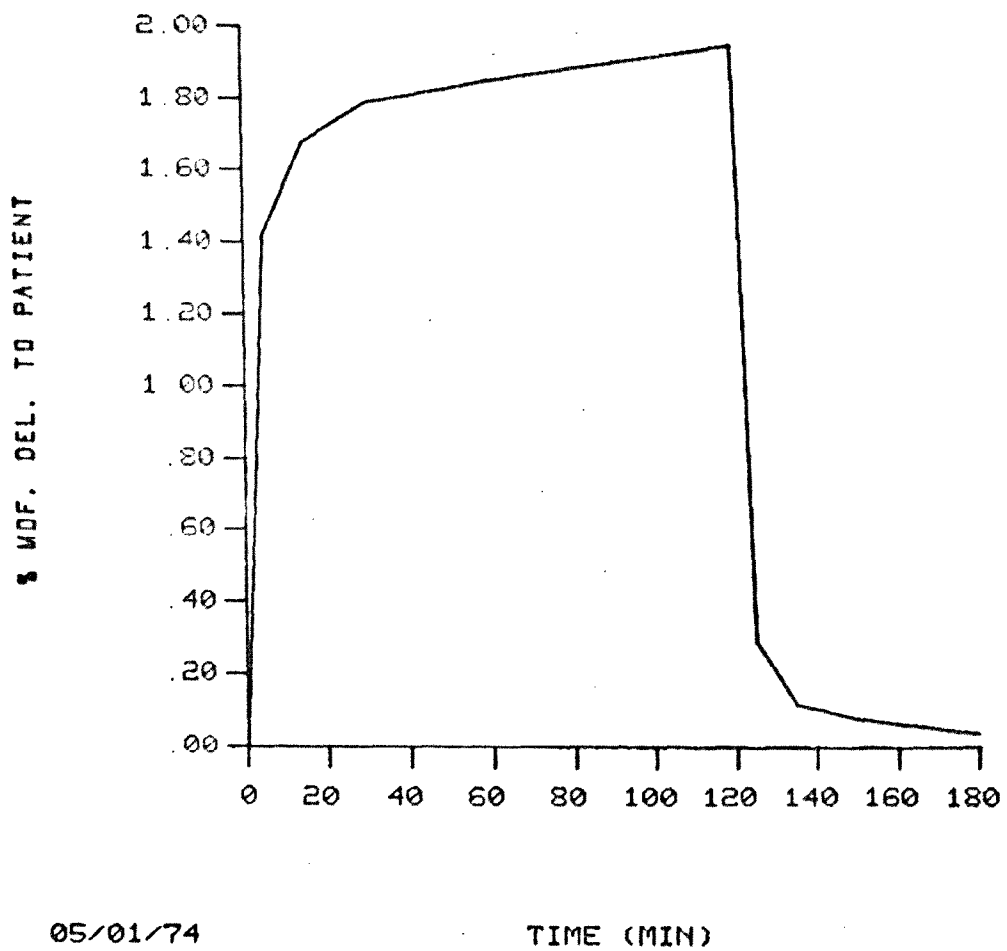
05/01/74   TIME (MIN)

FIGURE NO. 10

RUBBER (FOREGGER) 2% 2LPM
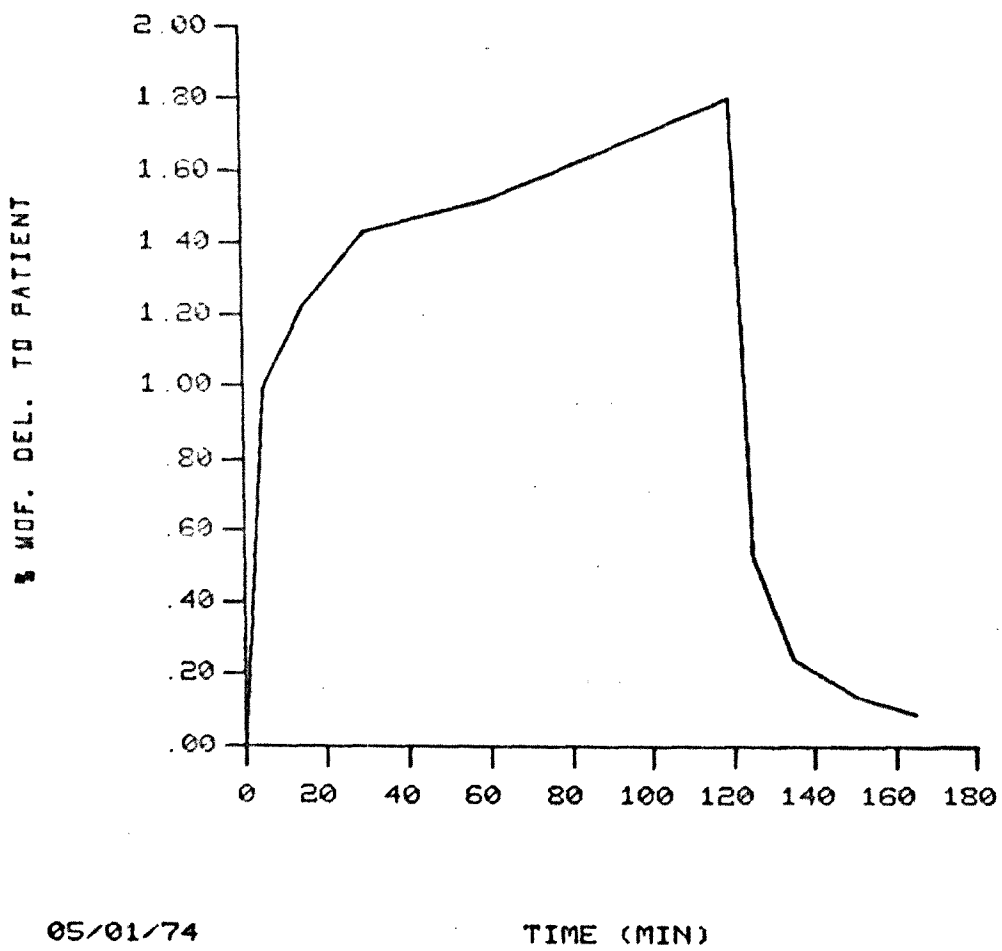
05/01/74

FIGURE NO. 11

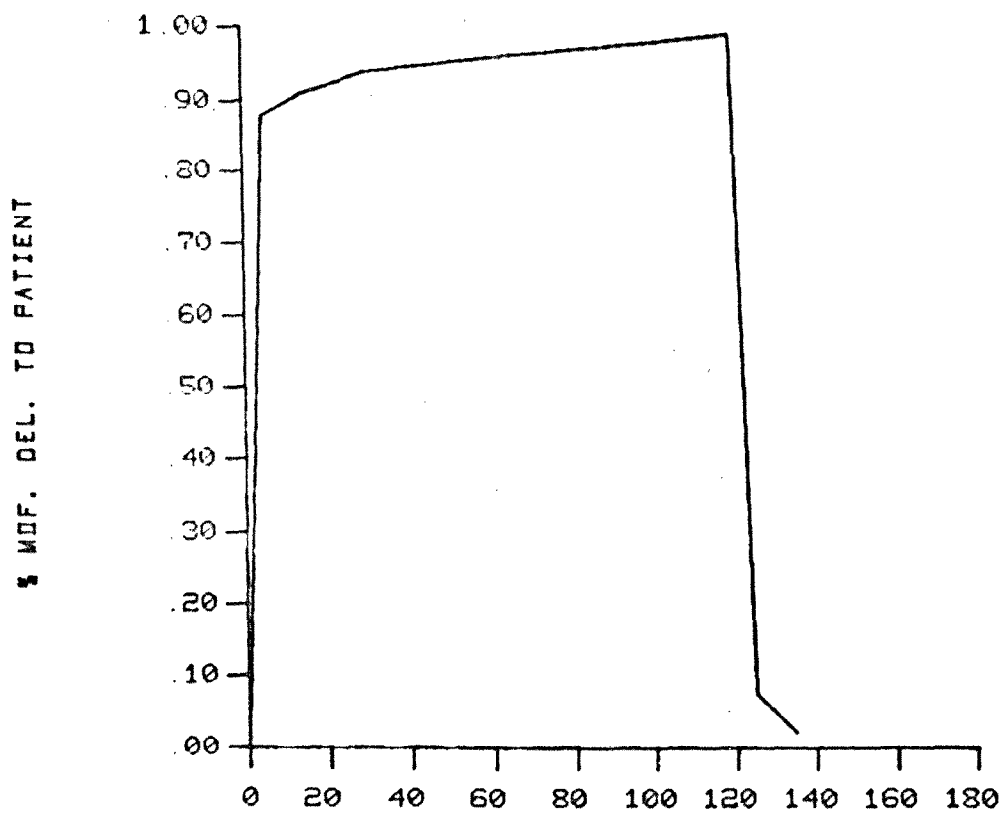RUBBER (DUPACO) 2% 2LPM
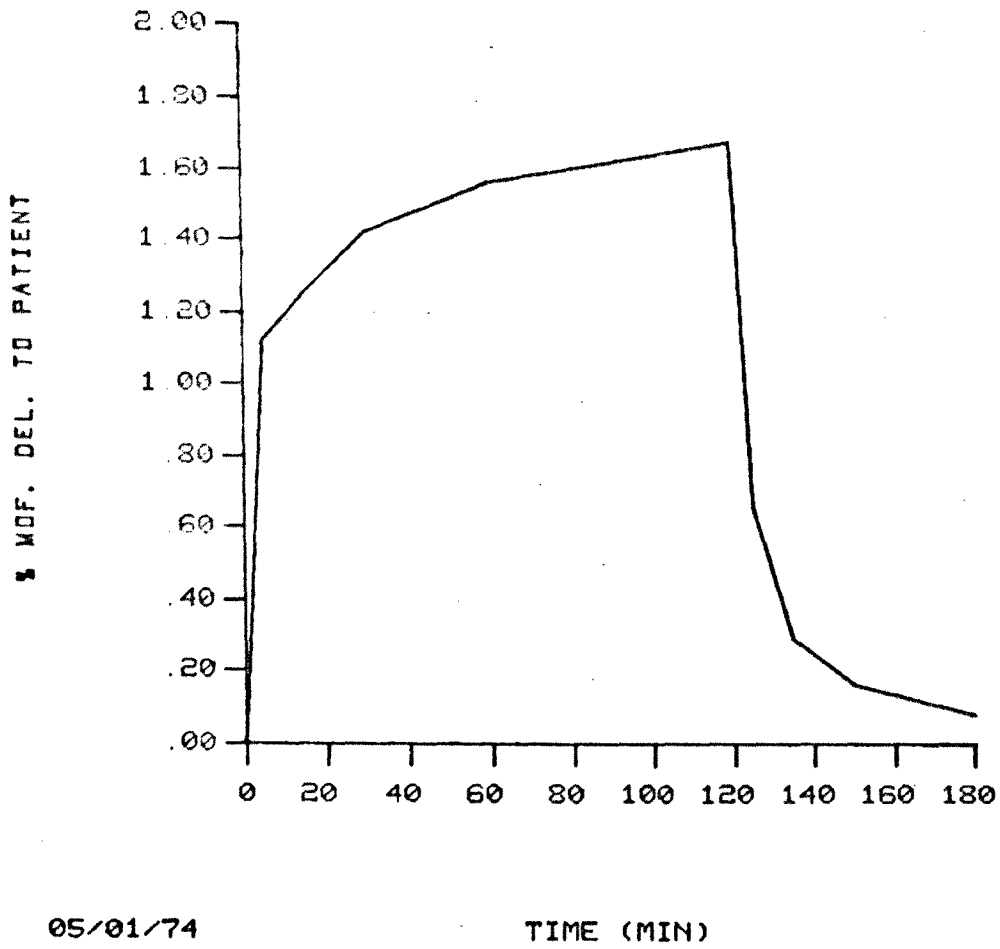
05/01/74   TIME (MIN)

FIGURE NO. 12

POLYETHYLENE (OHIO) 2% 2LPM
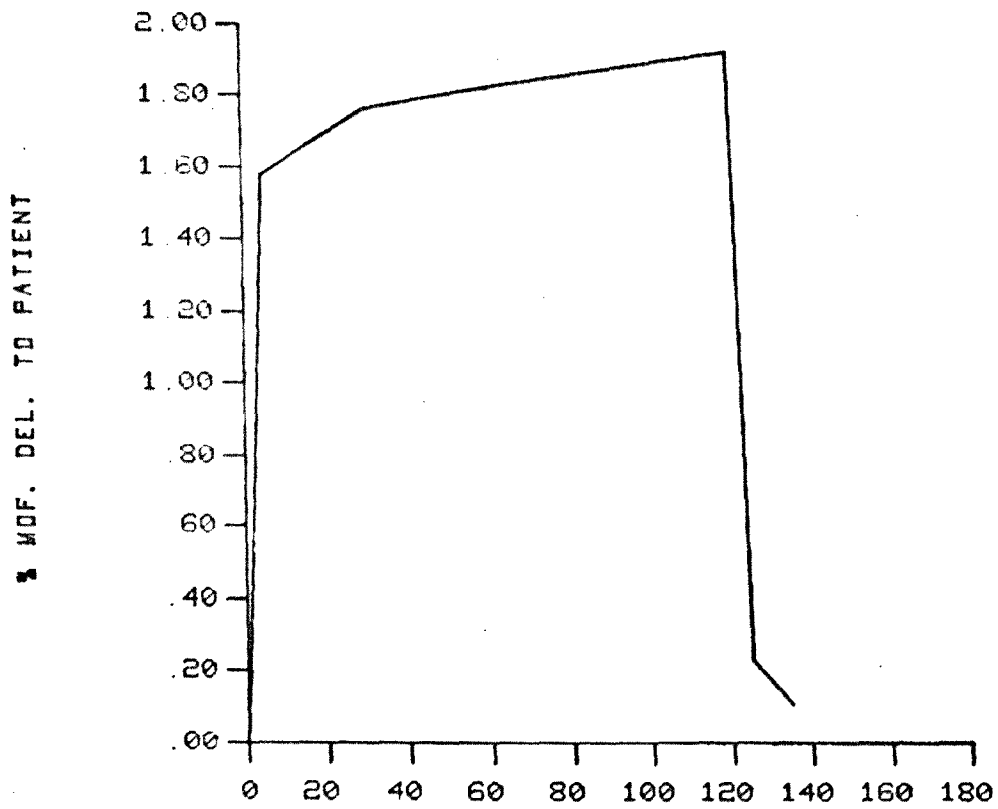
05/01/74   TIME (MIN)

FIGURE NO. 13

RUBBER (OHIO) 2% 2LPM
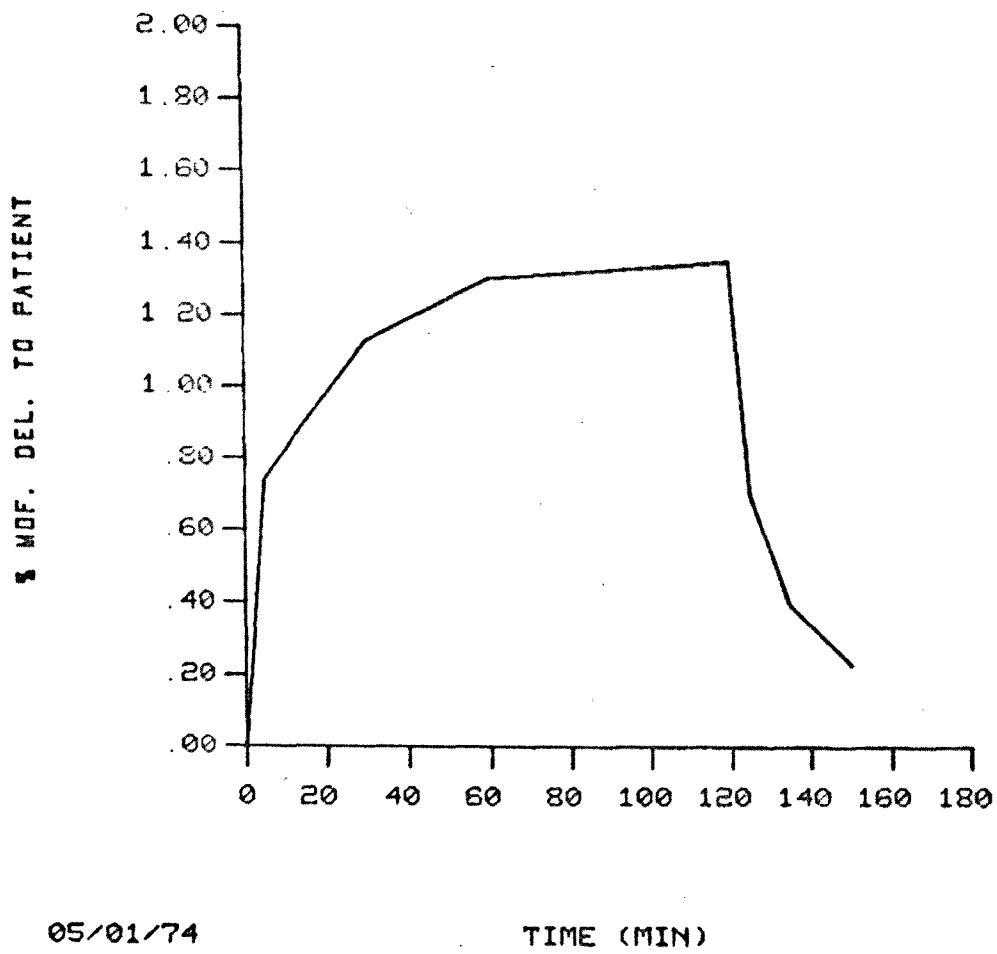
05/01/74 TIME (MIN)

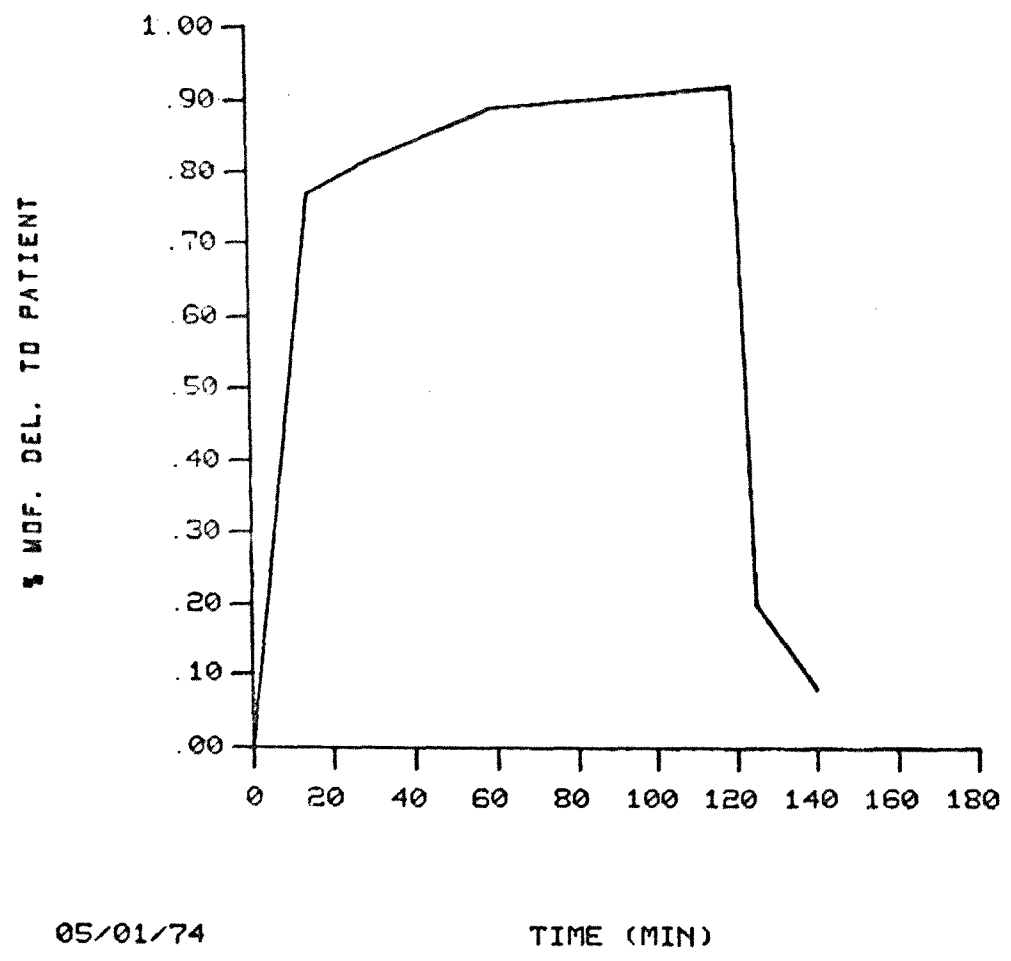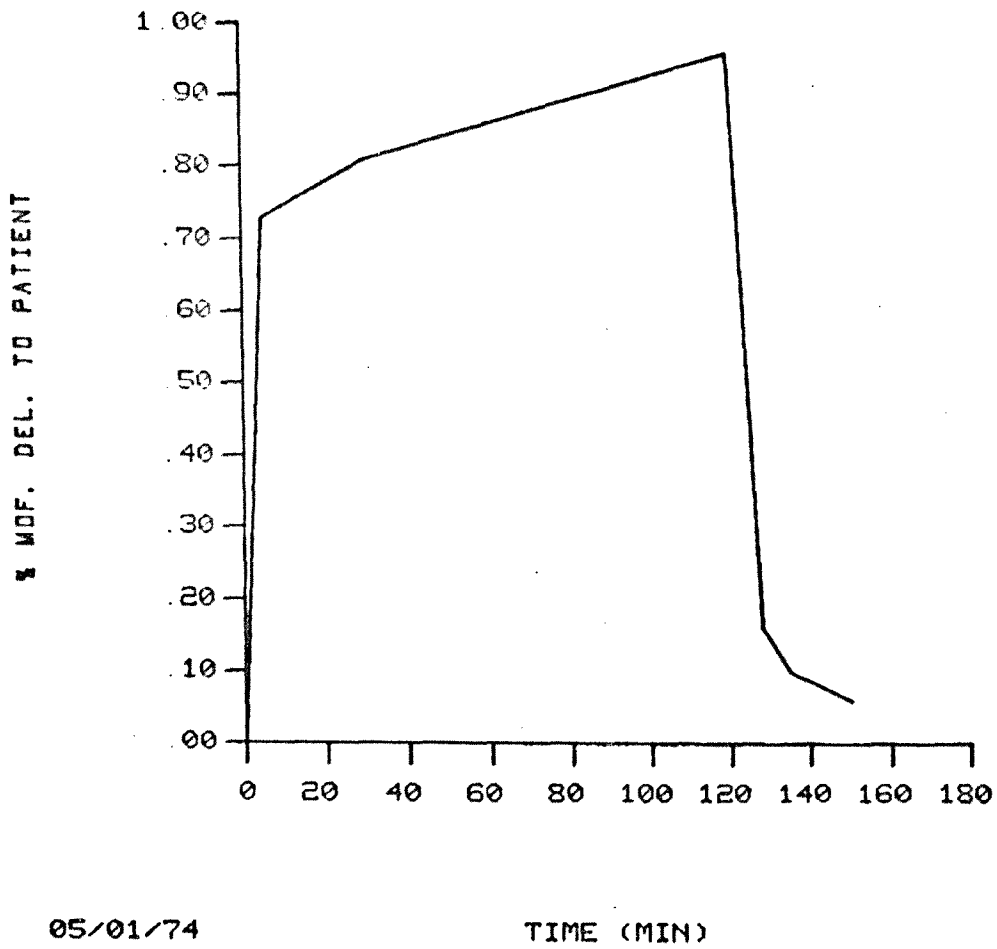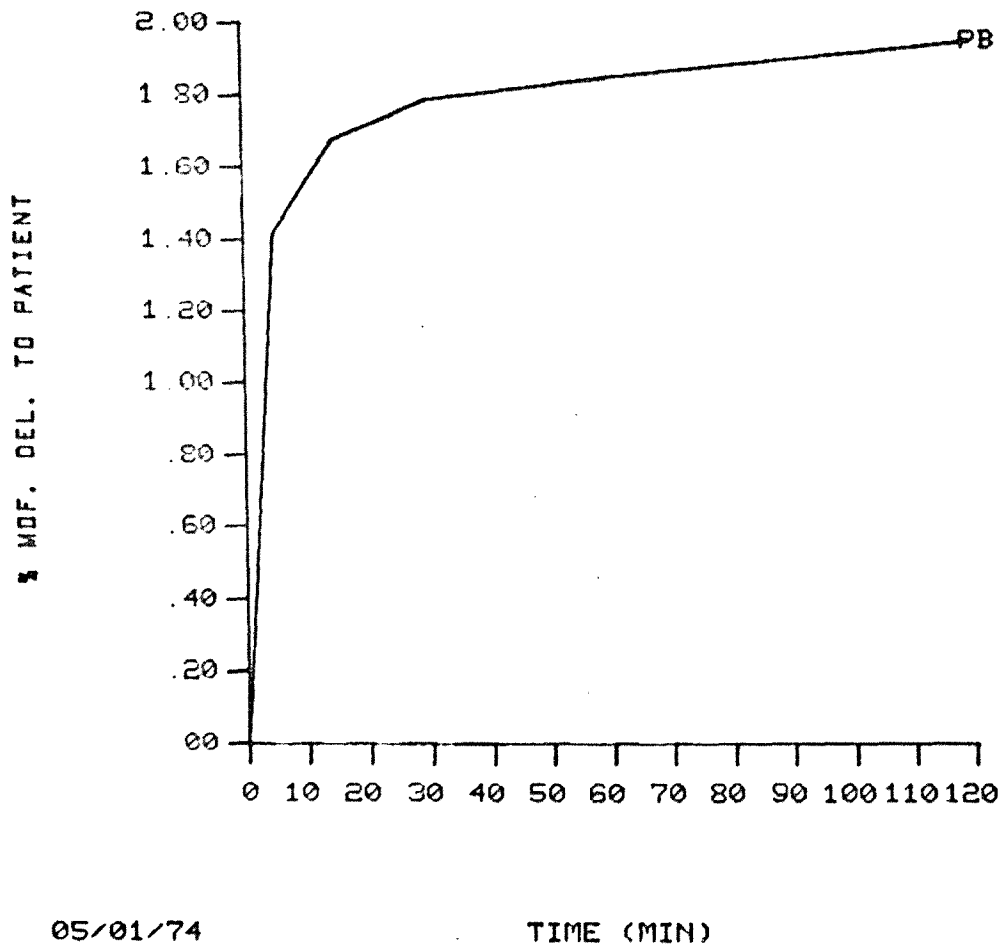FIGURE NO. 14

POLYETHYLENE (BARD-PARKER) 1% 2LPM

05/01/74   TIME (MIN)

FIGURE NO. 15

RUBBER (FOREGGER) 1% 2LPM

05/01/74   TIME (MIN)

FIGURE NO. 16

RUBBER (DUPACO) 1% 2LPM

05/01/74   TIME (MIN)

38

FIGURE NO. 17

ABSORPTION 2% 2LPM

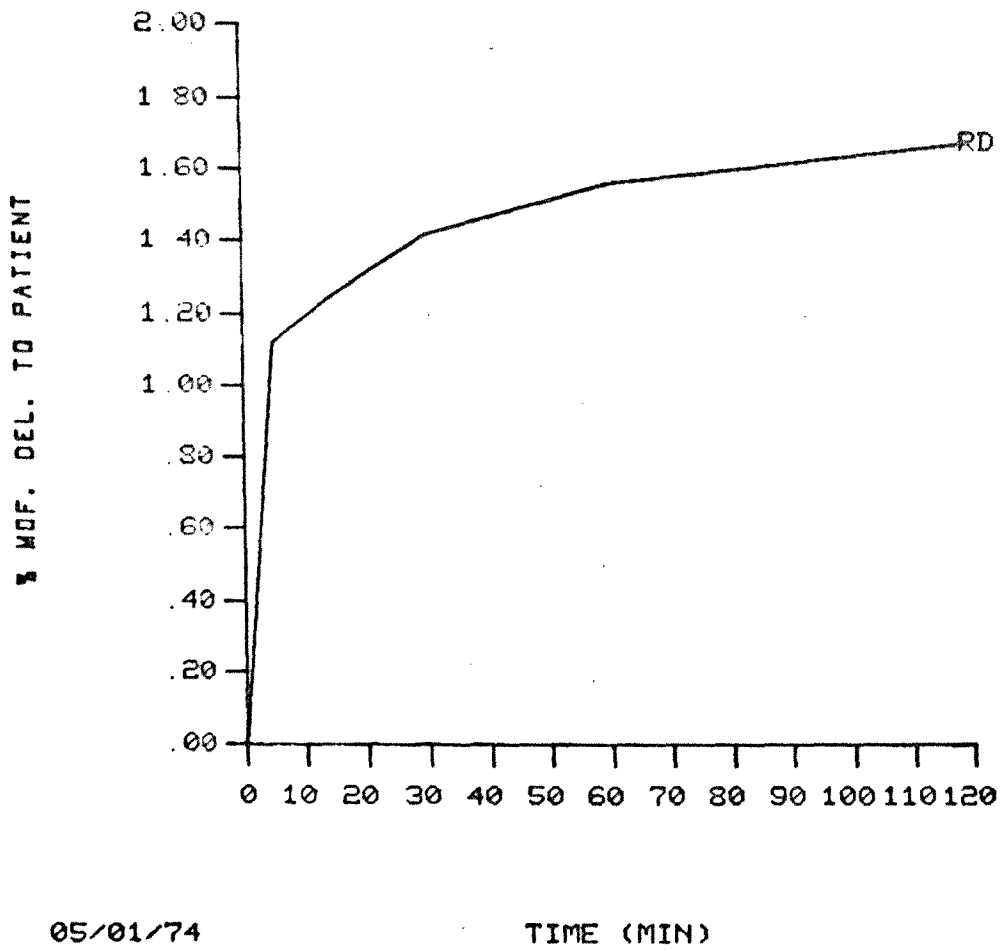05/01/74   TIME (MIN)

FIGURE NO. 18

ABSORPTION 2% 2LPM
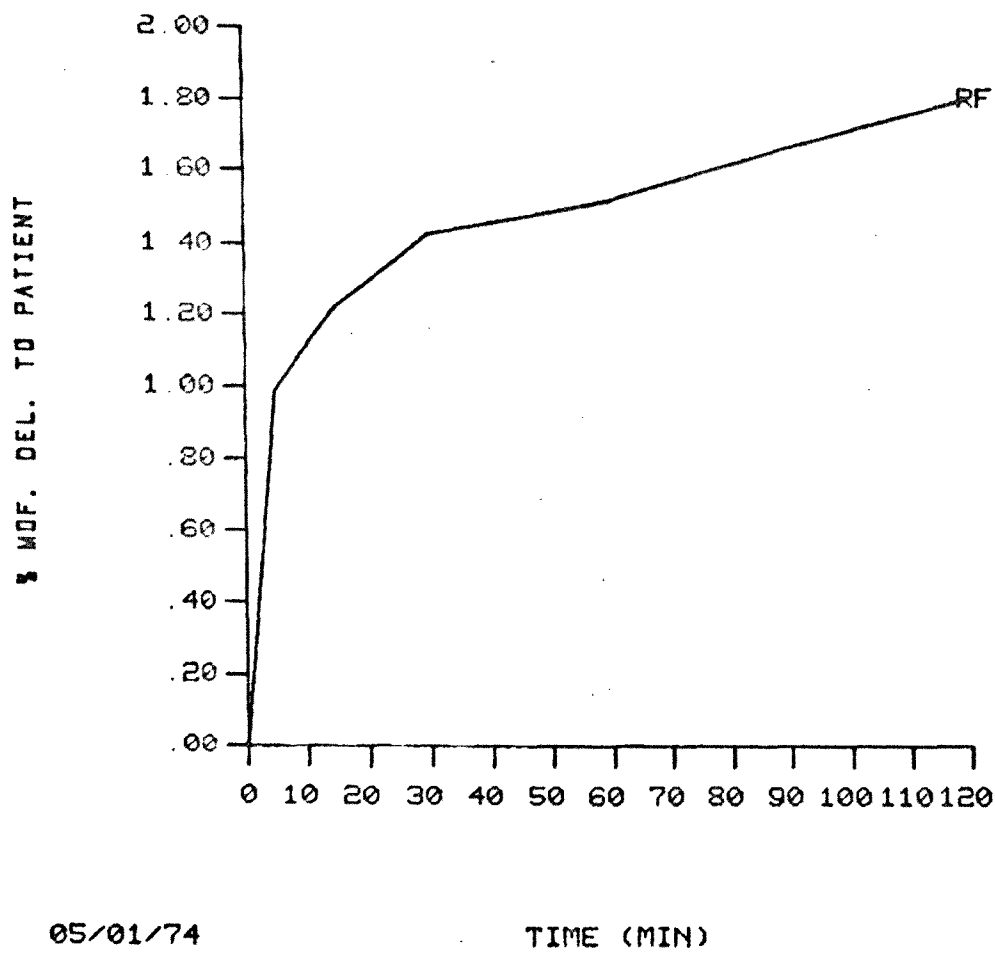
05/01/74   TIME (MIN)

FIGURE NO. 19

ABSORPTION 2% 2LPM

05/01/74   TIME (MIN)

FIGURE NO. 20

ABSORPTION 2% 2LPM

05/01/74

FIGURE NO. 21

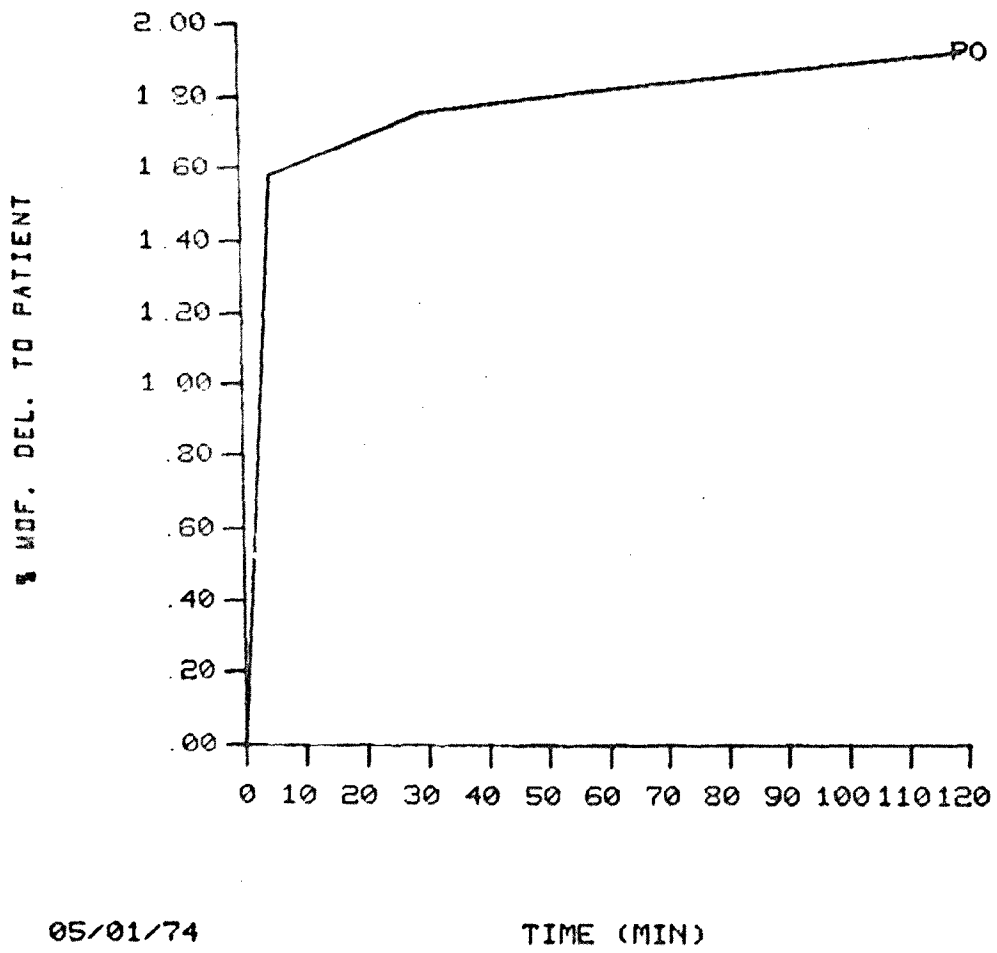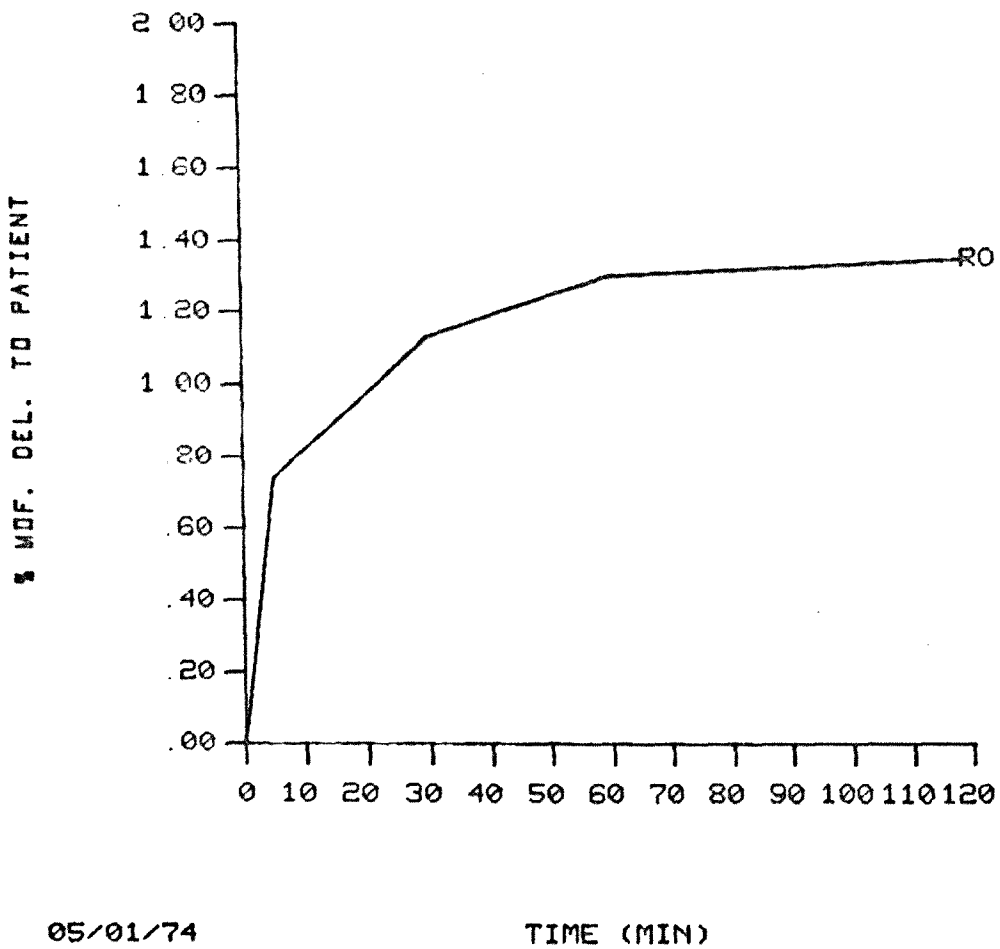ABSORPTION 2% 2LPM

05/01/74
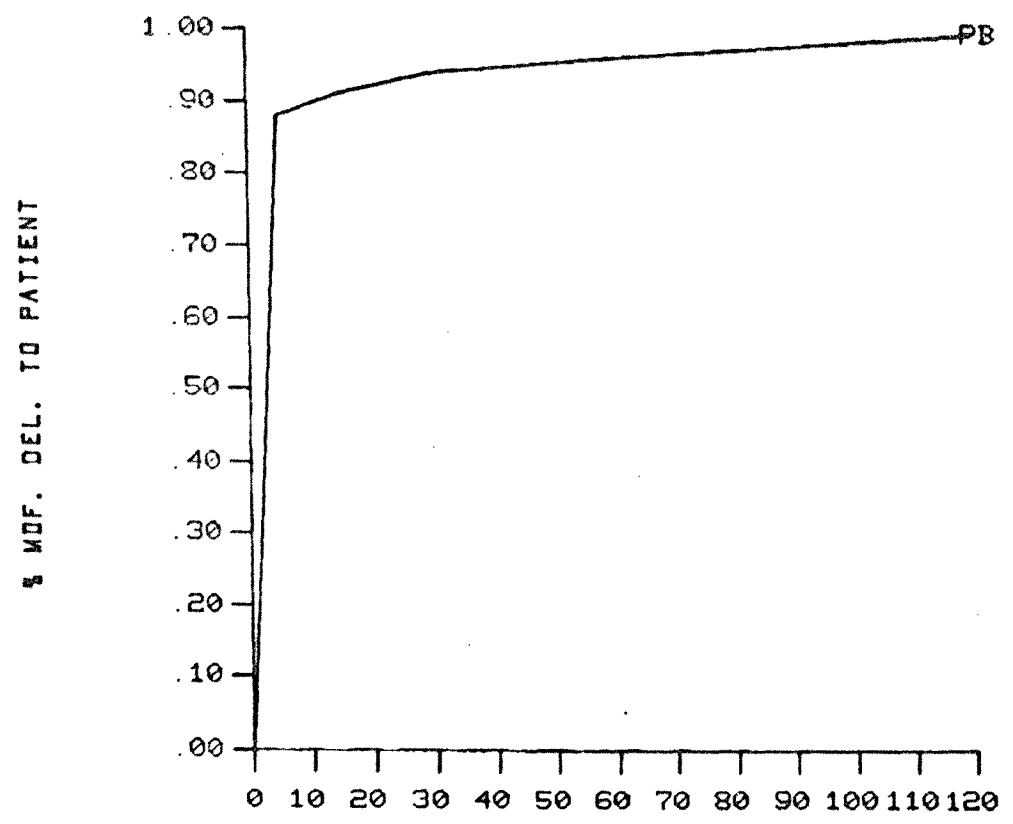
FIGURE NO. 22

ABSORPTION 1% 2LPM
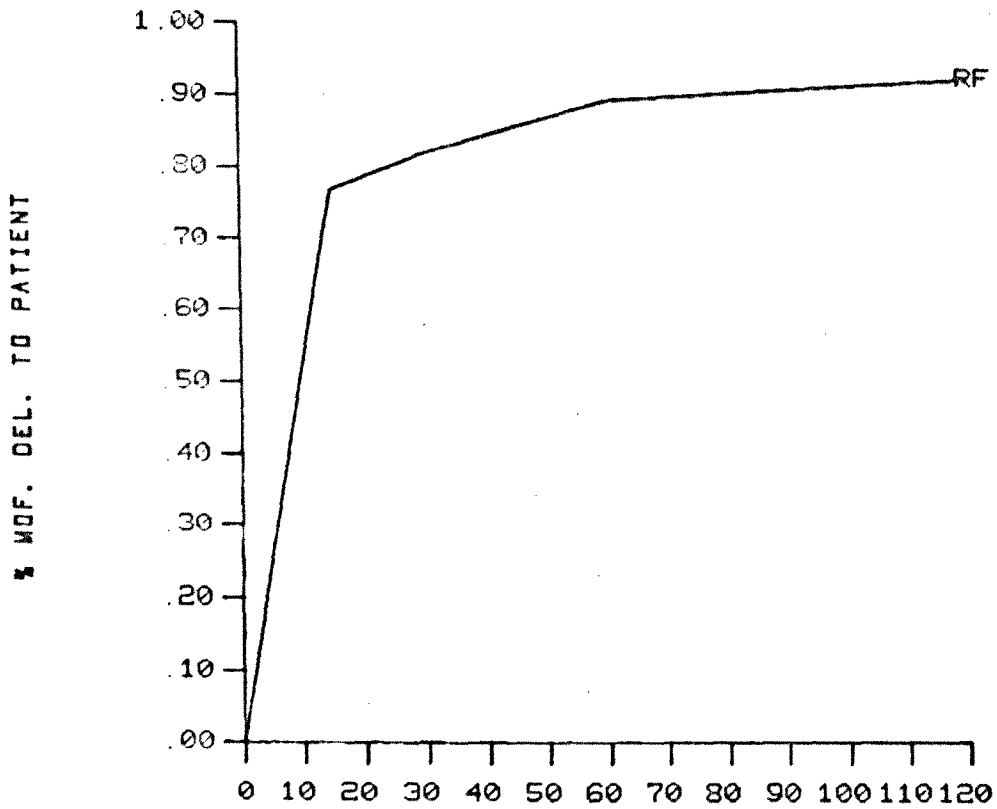

05/01/74   TIME (MIN)

FIGURE NO. 23

ABSORPTION 1% 2LPM

05/01/74   TIME (MIN)

FIGURE NO. 24
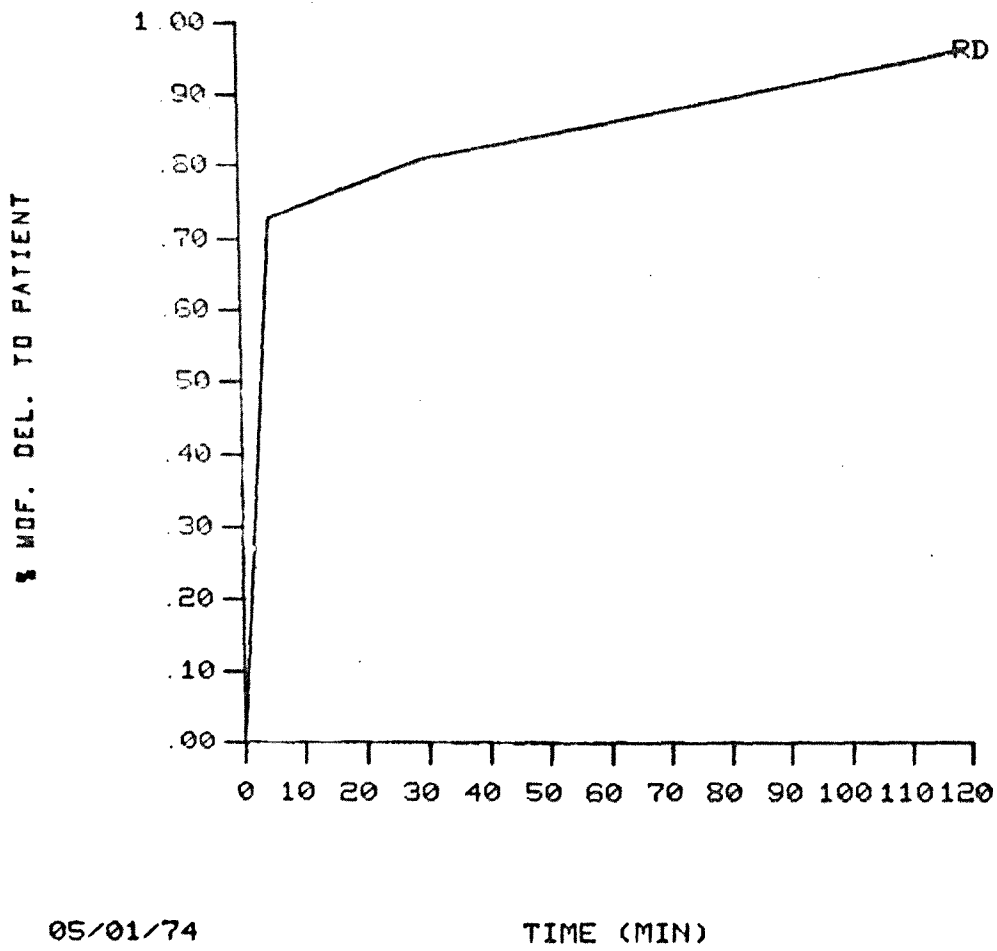
ABSORPTION 1% 2LPM

05/01/74   TIME (MIN)

FIGURE NO. 25

ABSORPTION 1% 2LPM

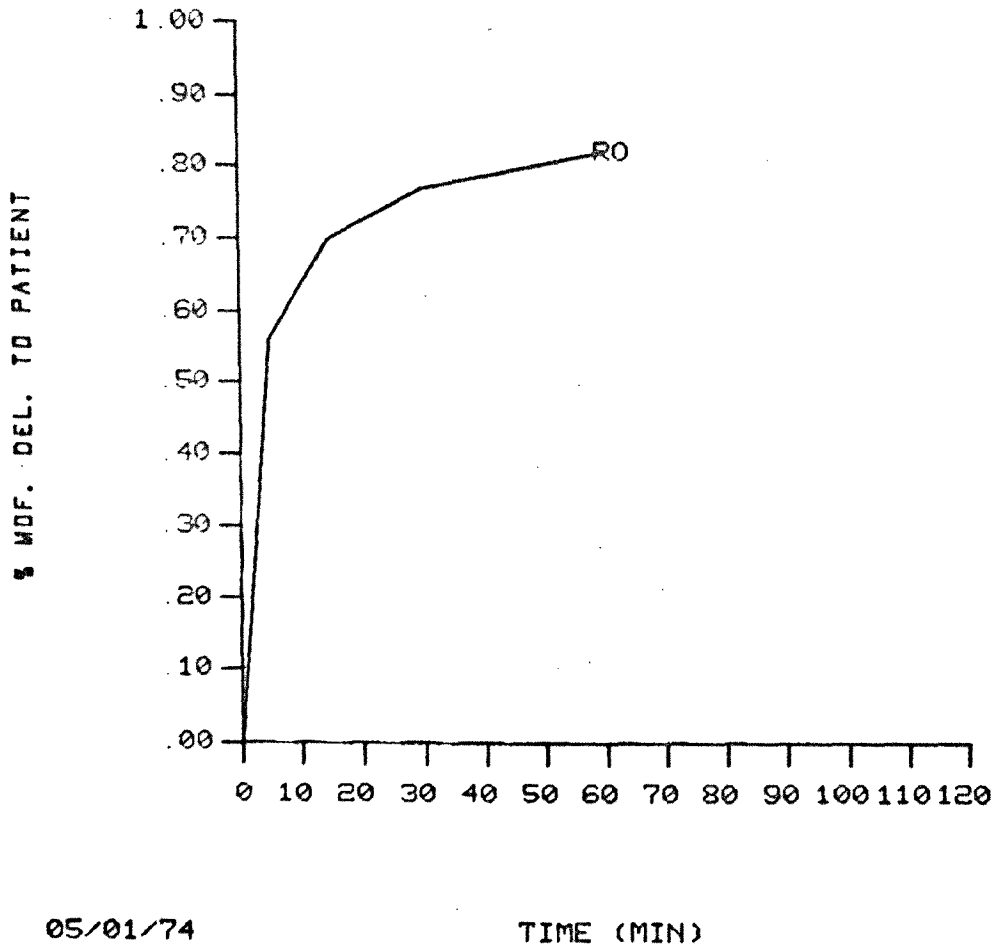05/01/74   TIME (MIN)

FIGURE NO. 26

ABSORPTION 2% 2LPM

05/06/74   TIME (MIN)

FIGURE NO. 27

ABSORPTION 1% 2LPM

05/06/74

TIME (MIN)
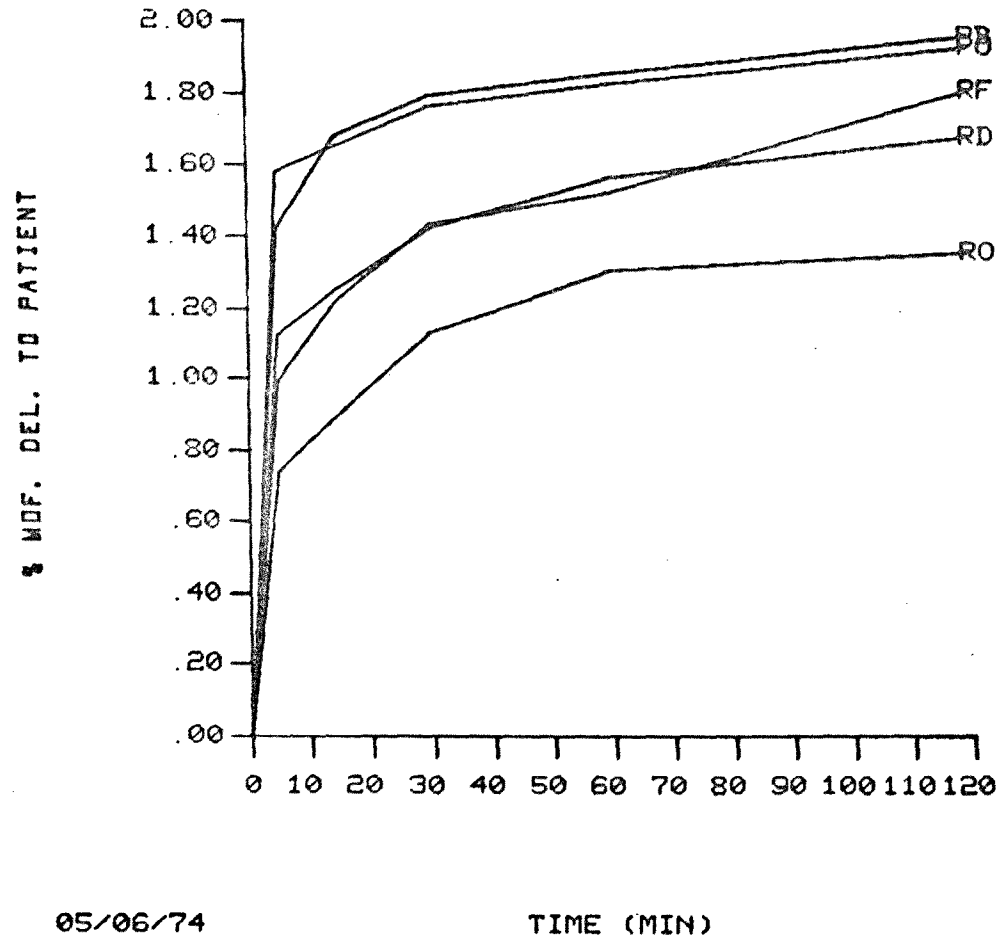
FIGURE NO. 28

DESORPTION 2% 2LPM

05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 29

DESORPTION 2% 2LPM

05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 30

DESORPTION 2% 2LPM

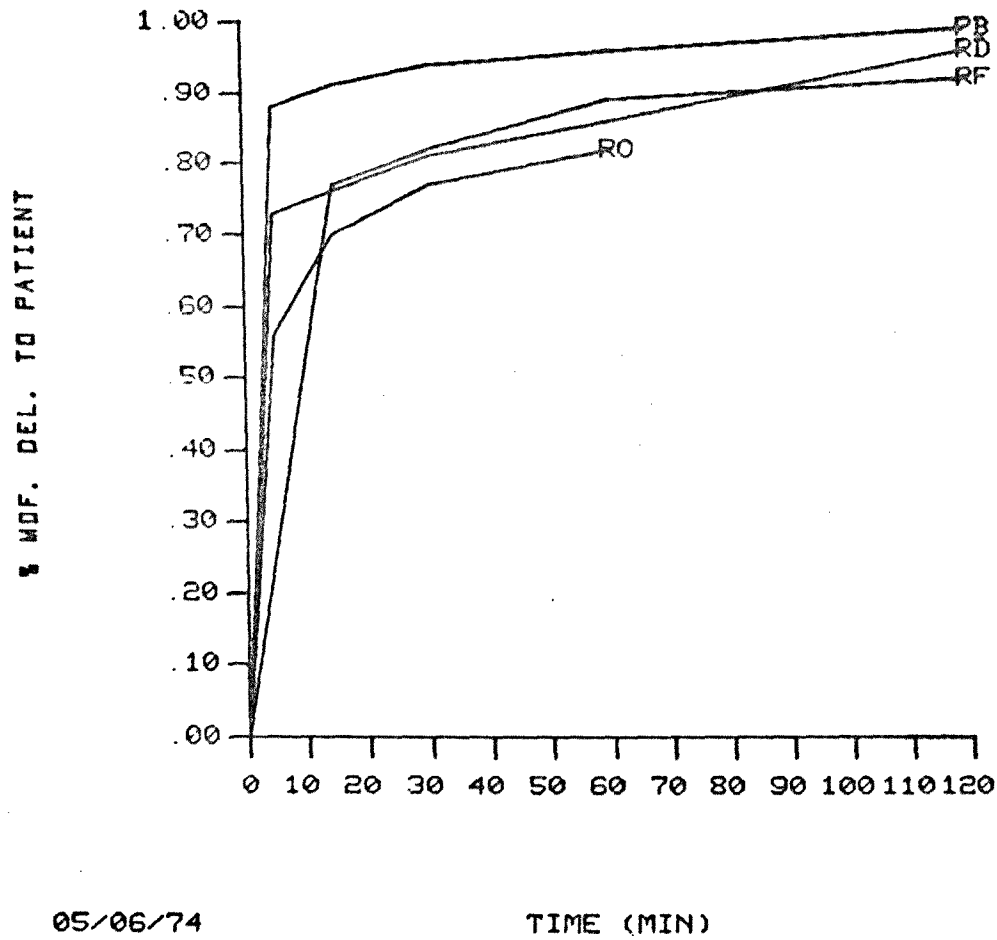05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 31

DESORPTION 2% 2LPM

05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 32

DESORPTION 2% 2LPM

05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 33

DESORPTION 1% 2LPM

05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 34

DESORPTION 1% 2LPM

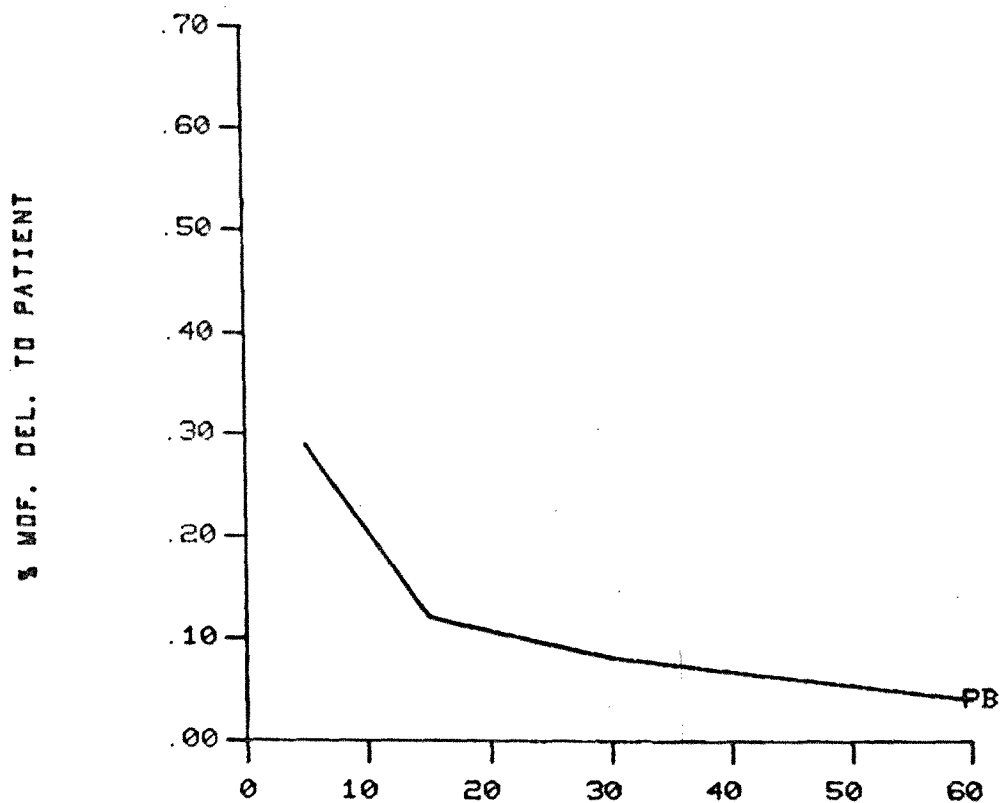
05/06/74

FIGURE NO. 35

DESORPTION 1% 2LPM

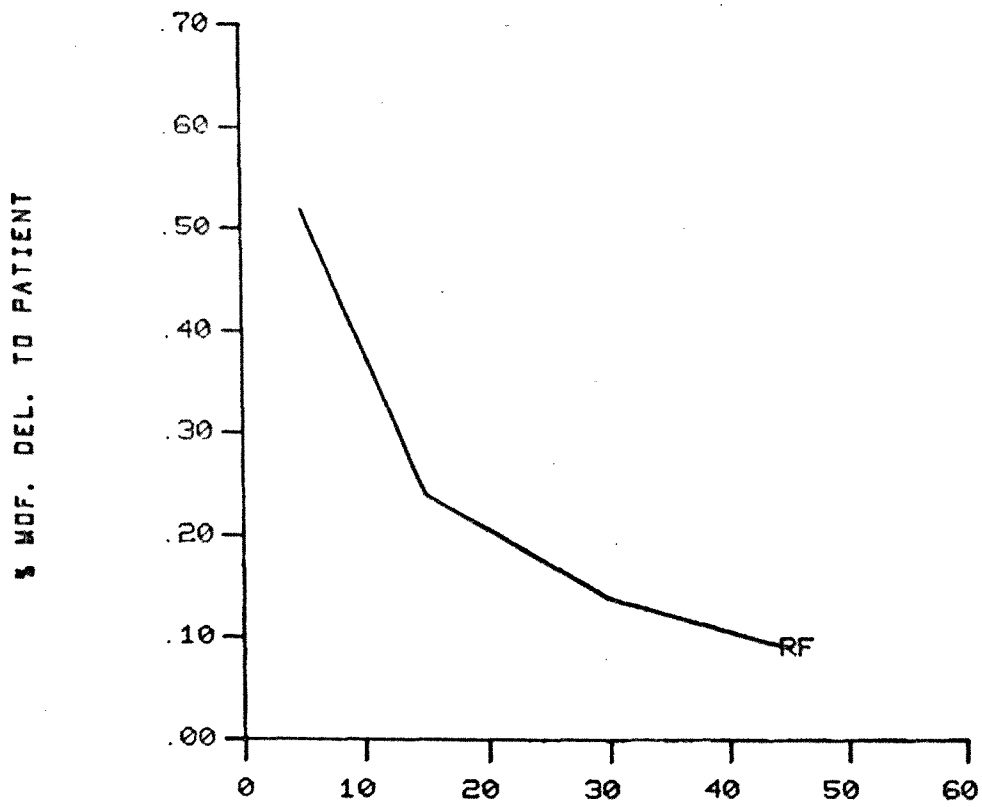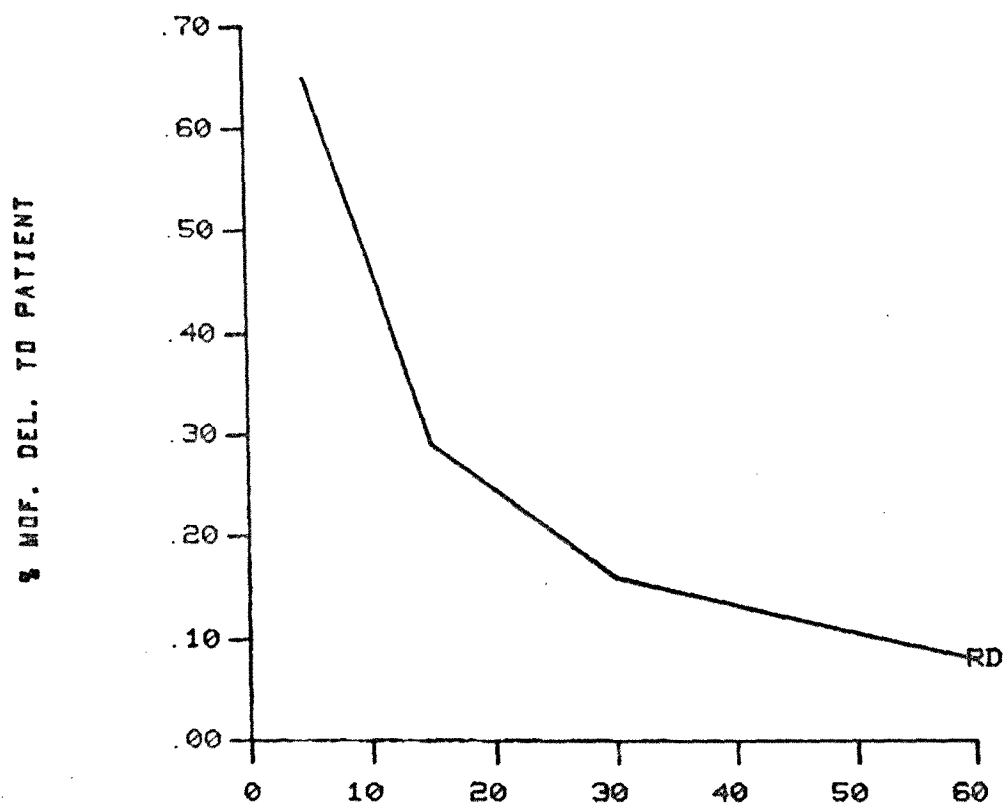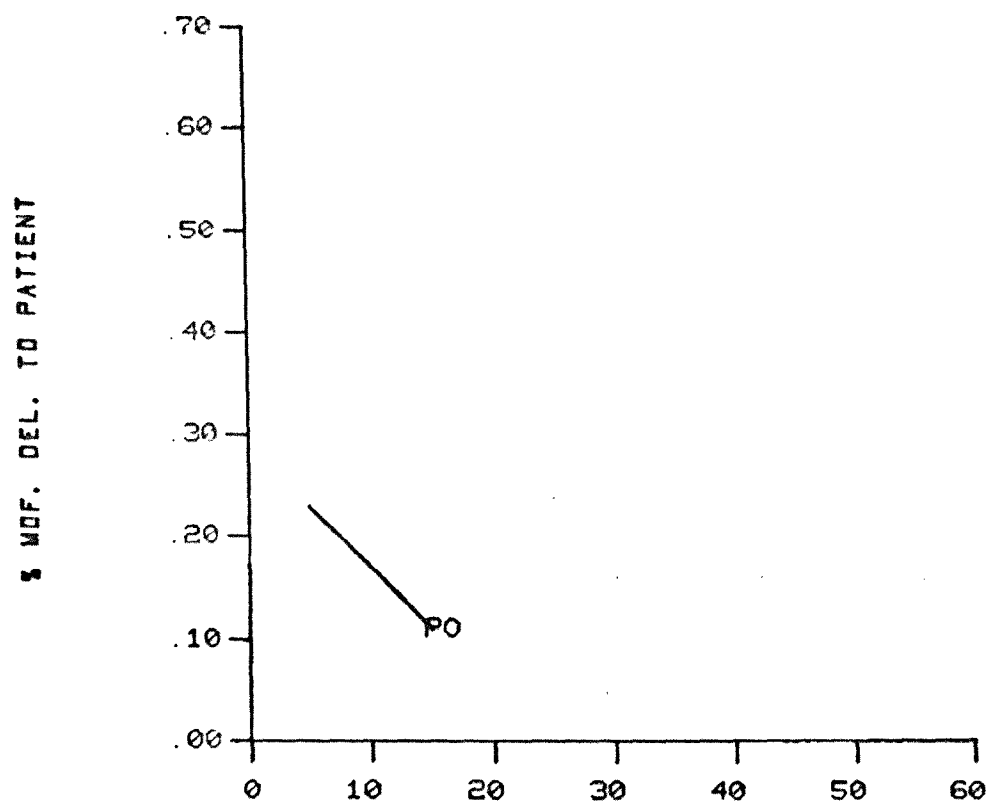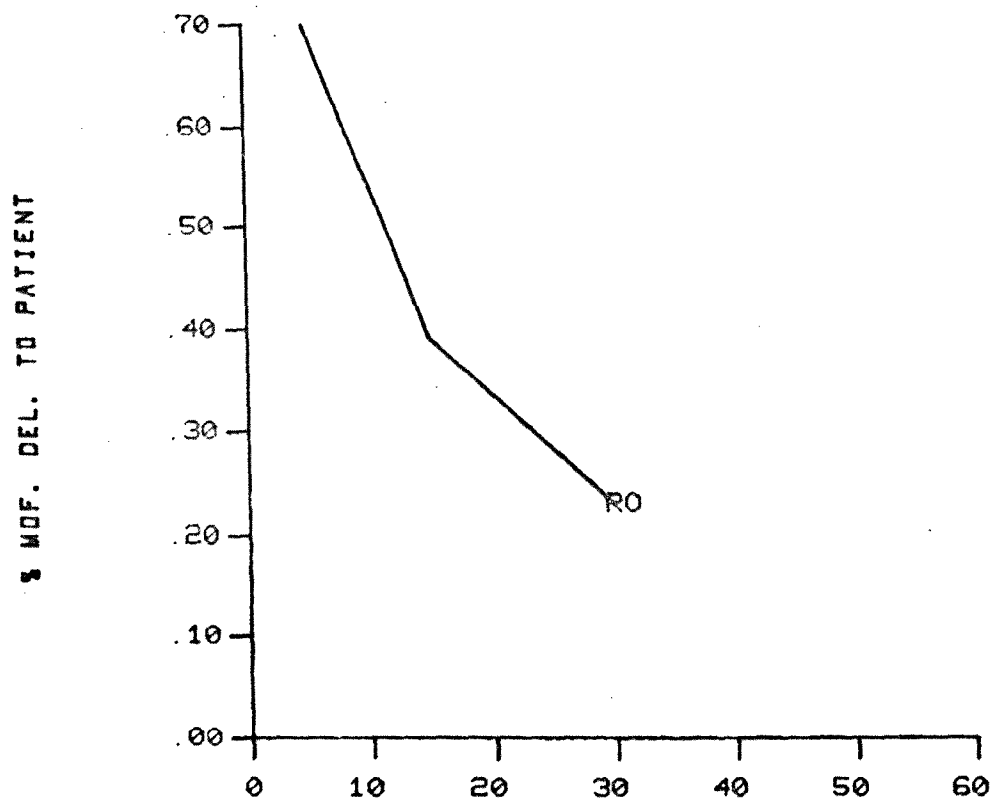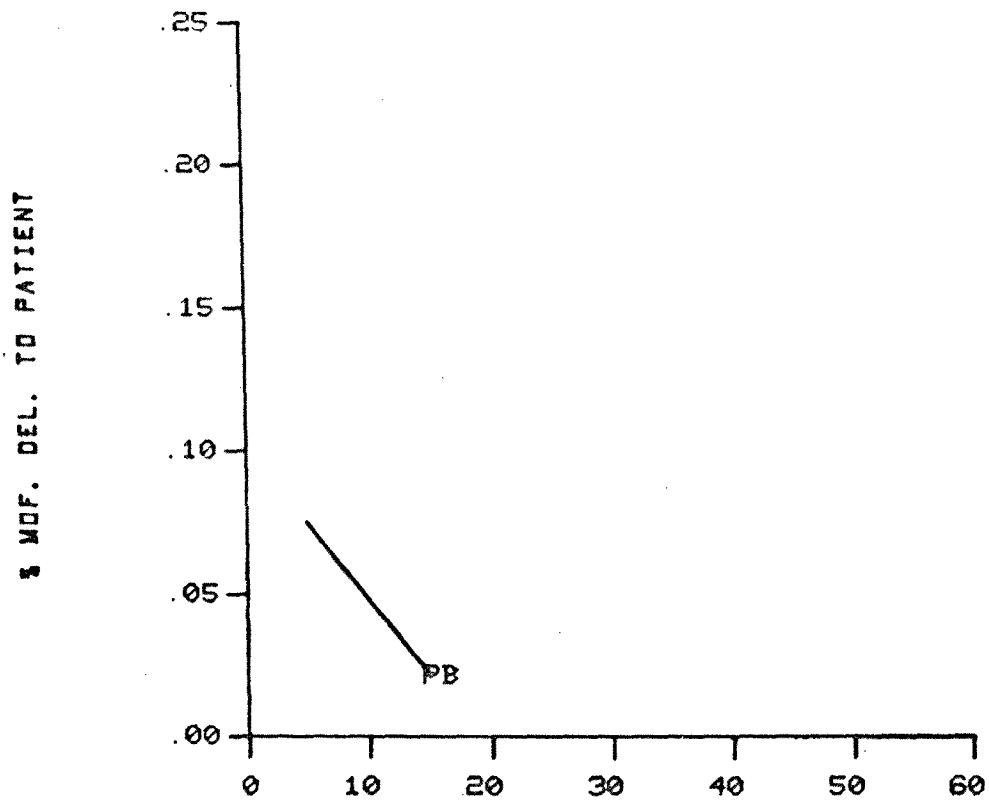05/06/74   WASHOUT TIME (MIN)
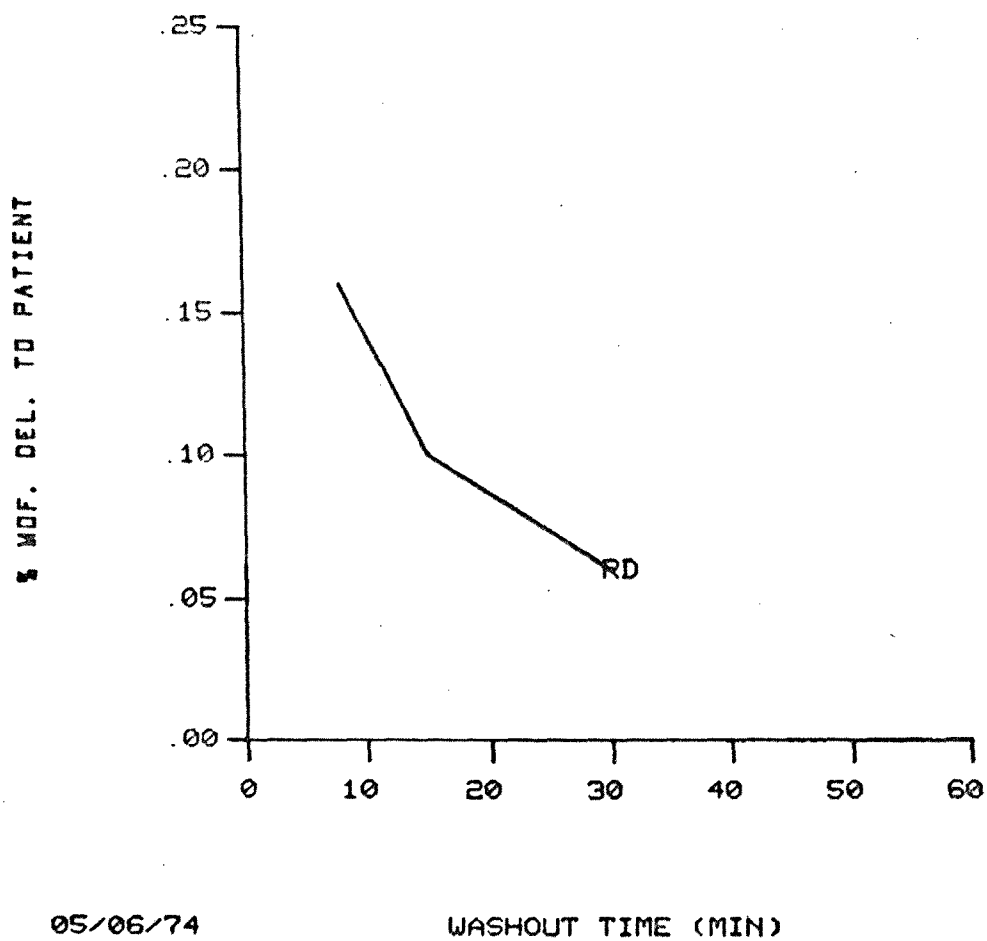
FIGURE NO. 36

DESORPTION 2% 2LPM

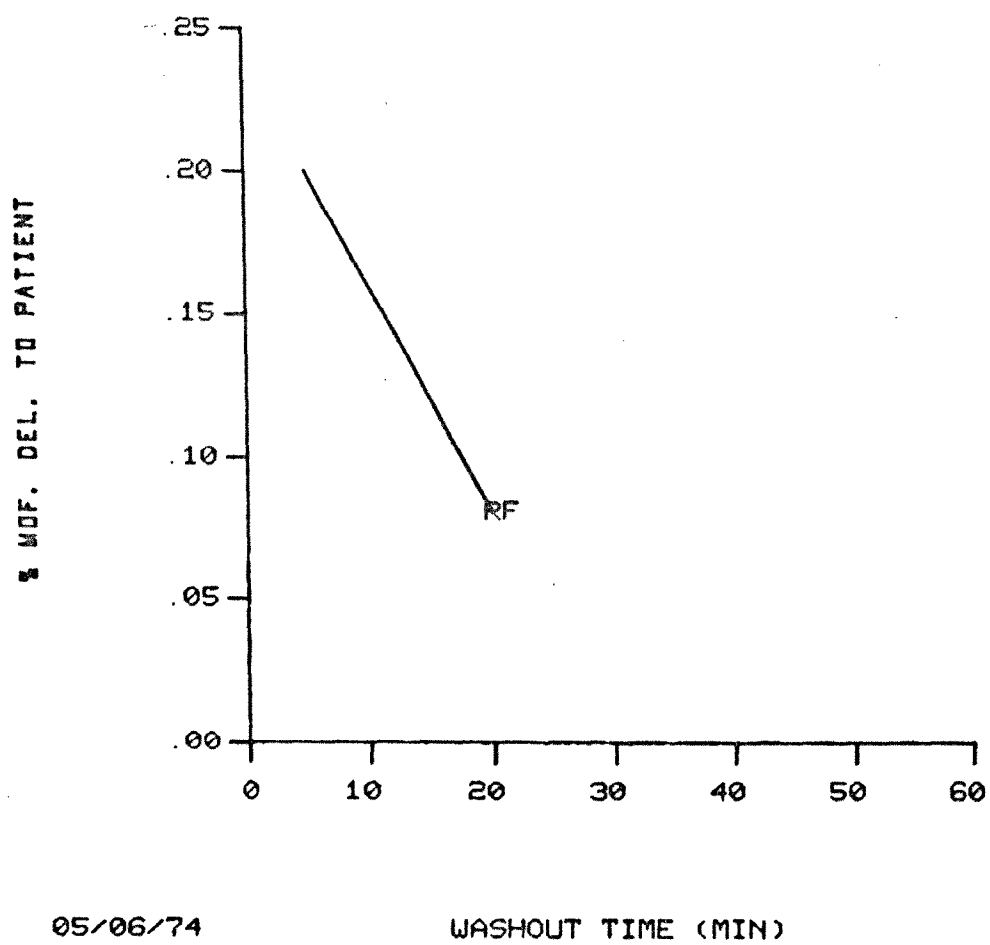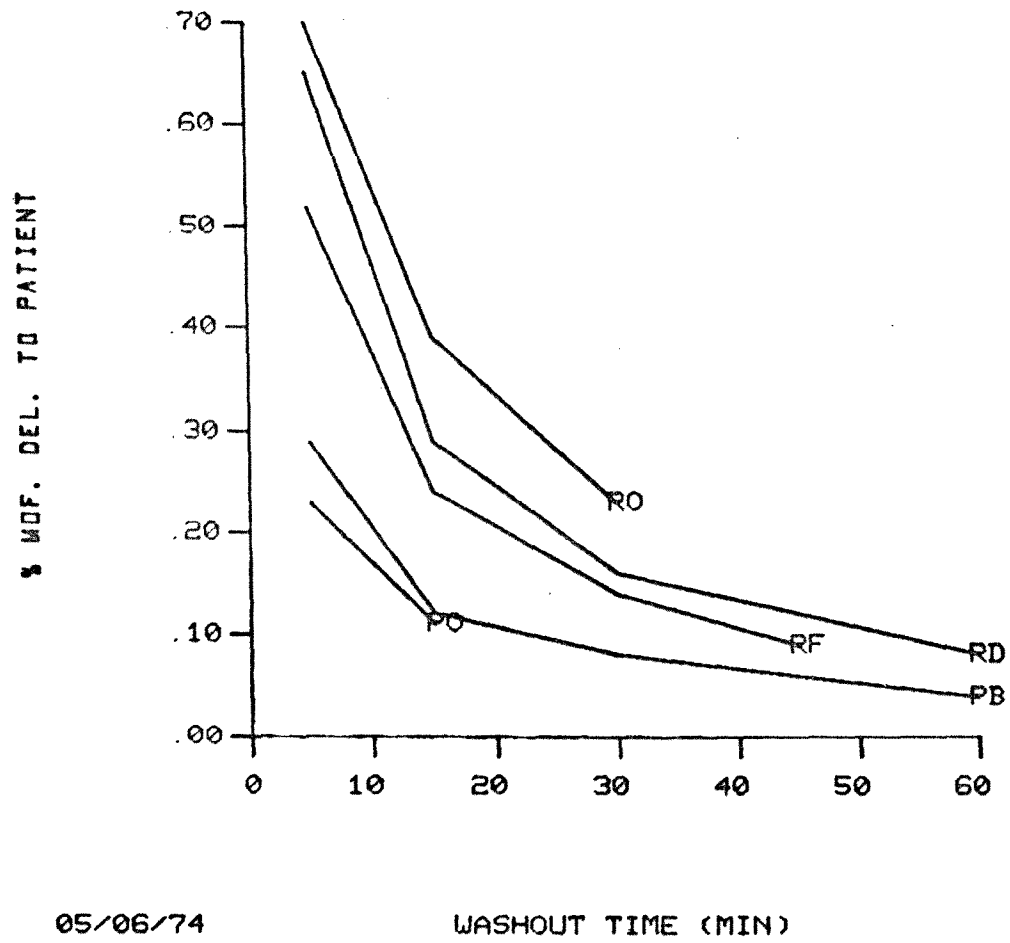05/06/74   WASHOUT TIME (MIN)

FIGURE NO. 37

DESORPTION 1% 2LPM

05/06/74   WASHOUT TIME (MIN)
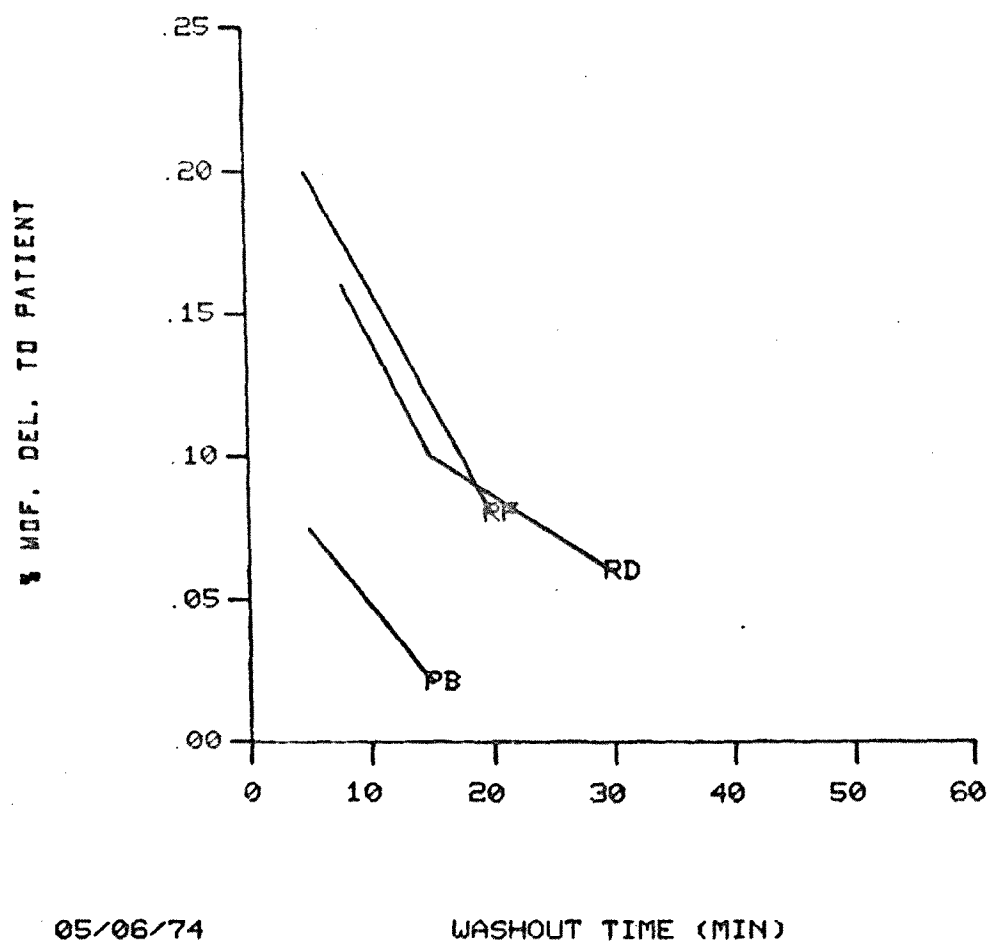
Chapter 8

DIFFUSION COEFFICIENTS

Lowe et al[17] calculated a diffusion coefficient for methoxy-
flurane in rubber hose (conductive – single length) at 0.5% concentra-
tion using equations 8 and 9. Assuming a partition coefficient of
630, the diffusion coefficient was stated to be 2.64×10^{-5} cm^2/min
$(D \lambda^2 = 10.47)$.

Figures 38, 39 and 40 depict the cumulative anesthetic uptake
at 2% methoxyflurane and 2 LPM, 2% methoxyflurane and 5 LPM and 1%
methoxyflurane and 2 LPM respectively from measured weight gain.
The slopes from linear regression of the data for each curve are
presented in table 2 along with diffusion coefficients $(D \lambda^2)$ calculated
from equation 8. $D \lambda^2$ was used because the partition coefficients
of the individual materials were not known. From the information
presented in Lowe[17] it was surmised that the rubber hose tested was
Ohio's.

From the results of this experiment it can be concluded that an
increase in flow rate does not affect diffusion in rubber hose
(conductive). Although the decrease in polyethylene diffusion coef-
ficient with increased flow cannot be explained sufficiently, it is
assumed that the relatively low diffusion rate coupled with decreased
contact time is a factor.

Decreasing system concentration can be seen to decrease diffusion coefficient. Thus diffusion in these materials is a function of concentration and not a constant as assumed by Lowe in the derivation of equations 8 and 9.

Figures 41 and 42 present uptake rates for 2% methoxyflurane and 2 LPM and 1% methoxyflurane and 2 LPM respectively calculated from gas chromatographic data from effluent measurements. Table 3 presents the same data as in Table 2 calculated using equation 9. The diffusion coefficients obtained are generally higher than those calculated from weight gain but show the same trends. Until more data is obtained covering a larger range of conditions it is not useful to speculate regarding the reason for this discrepancy. It is possible that evaporation losses might have effected the weight gain data.

Since it is obvious that diffusion of methoxyflurane in conductive hose materials is a function of system concentration, it was decided to calculate theoretical coefficients using Park's[20] method. Figure 43 is a plot of $D\lambda^2c$ versus C using averages between the weight gain and gas chromatographic data for Ohio rubber and Bard-Parker polyethylene. The intercepts are 5.1 and 0.3 respectively. From figure 6 the values of I at each D/D_0 can be obtained. Table 4 presents this data.

Using equation 10 it is possible to calculate theoretical diffusion coefficients for both materials. Figure 44 shows the theoretical relationships obtained and compares these with the experimental results

Obtained from table 3 and Lowe[17] (Ohio Rubber at 0.5% concentration). Although not precise, the fits are reasonably good at low concentrations.

Use of a gas chromatograph with thermal conductivity detection is not recommended since response time is lengthened due to oxygen interference. Flame ionization detection is more accurate and insensitive to oxygen thus permitting more frequent sampling.

FIGURE NO. 38

CUM ANES. UPTAKE 2% 2LPM

05/06/74   SQUARE ROOT OF TIME (MIN)
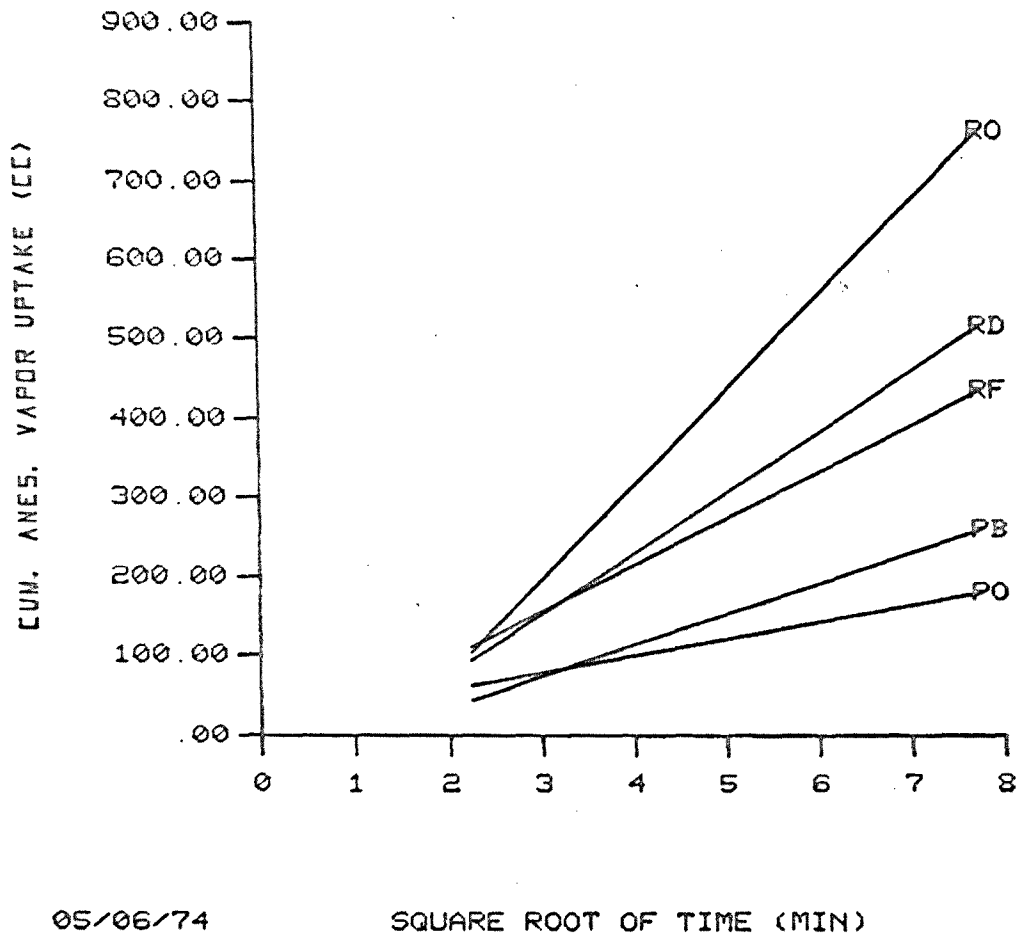
FIGURE NO. 39

CUM ANES. UPTAKE 1% 2LPM
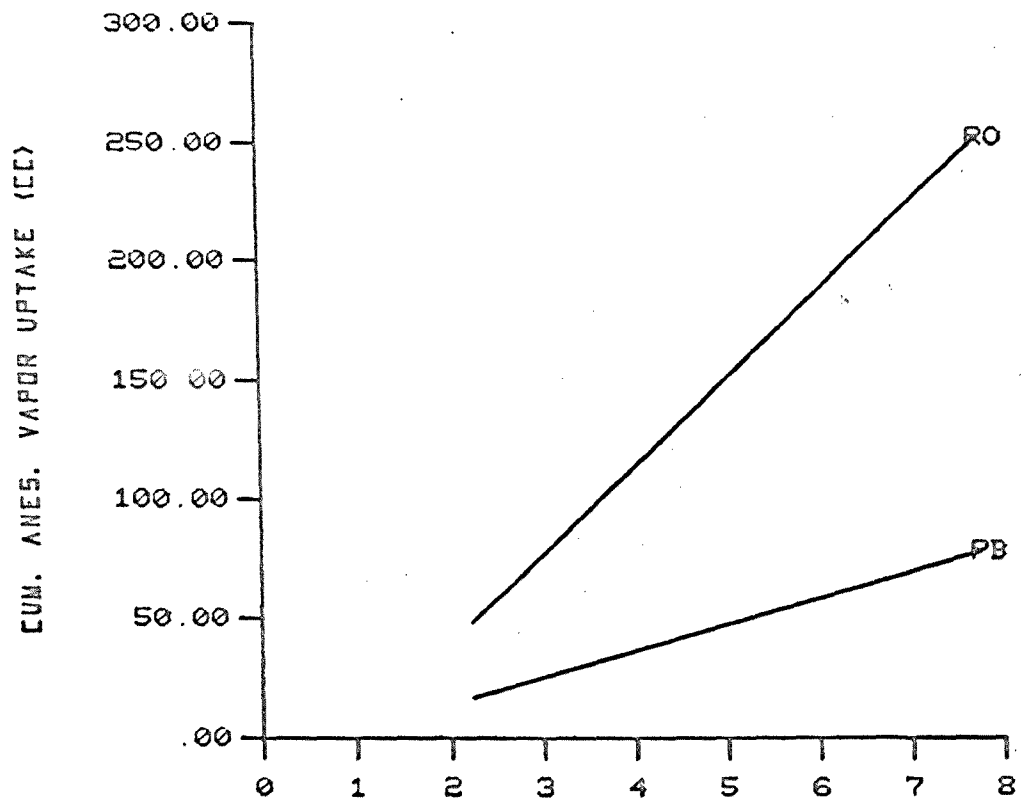
05/06/74   SQUARE ROOT OF TIME (MIN)

FIGURE NO. 40

CUM ANES. UPTAKE 2% 5LPM
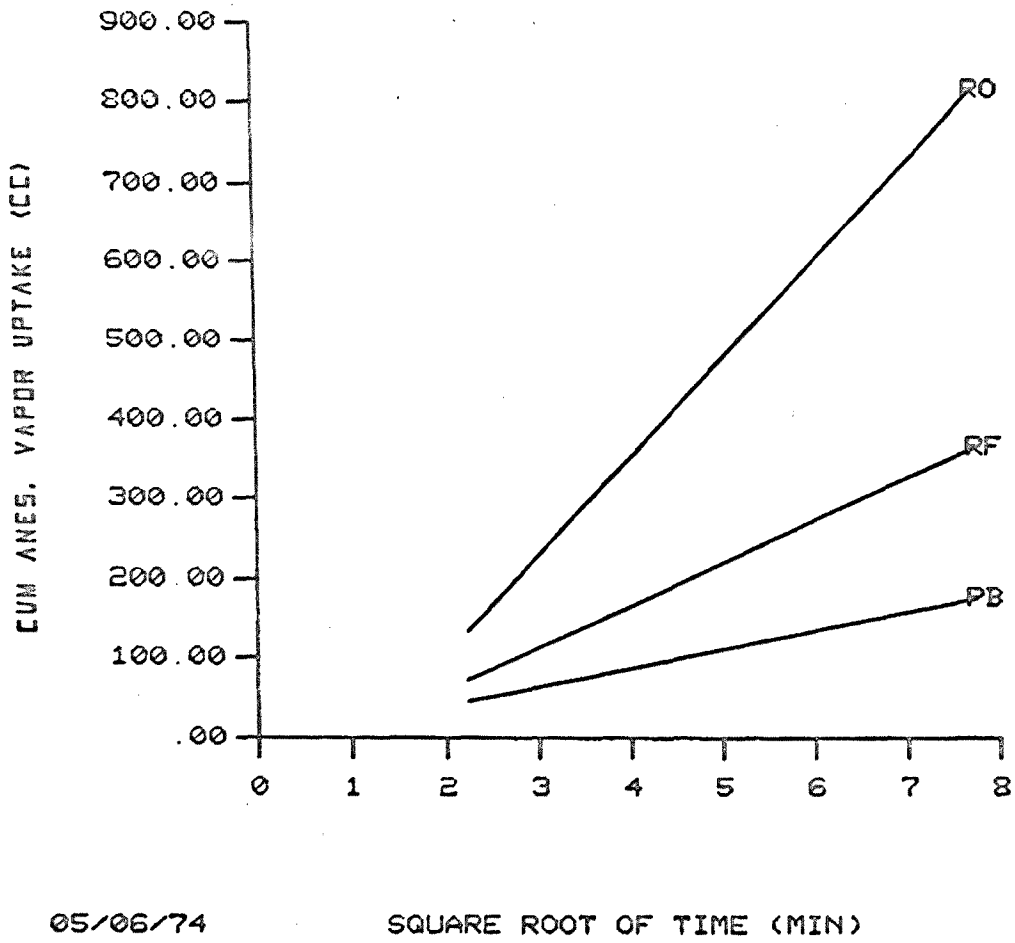
Table #2 - Calculation of Diffusion Coefficients ($D\lambda^2$)

Ref: Figures 38,39 and 40
Equation no. 8

Material	Manufacturer	2% 2 LPM		2% 5 LPM		1% 2 LPM	
		Slope	$D\lambda^2$	Slope	$D\lambda^2$	Slope	$D\lambda^2$
Rubber	Ohio (RO)	119.1	63.4	123.2	67.6	36.9	24.1
	Foregger (RF)	58.6	12.3	53.1	10.0	----	----
	Dupaco (RD)	76.3	48.0	-----	----	----	----
Polyethylene	Bard-Parker (PB)	38.6	5.3	23.5	2.0	11.2	1.8
	Ohio (PO)	21.2	3.3	-----	----	----	----

FIGURE NO. 41

VAPOR UPTAKE RATE 2% 2LPM

05/06/74   1/(SQUARE ROOT OF TIME (MIN))
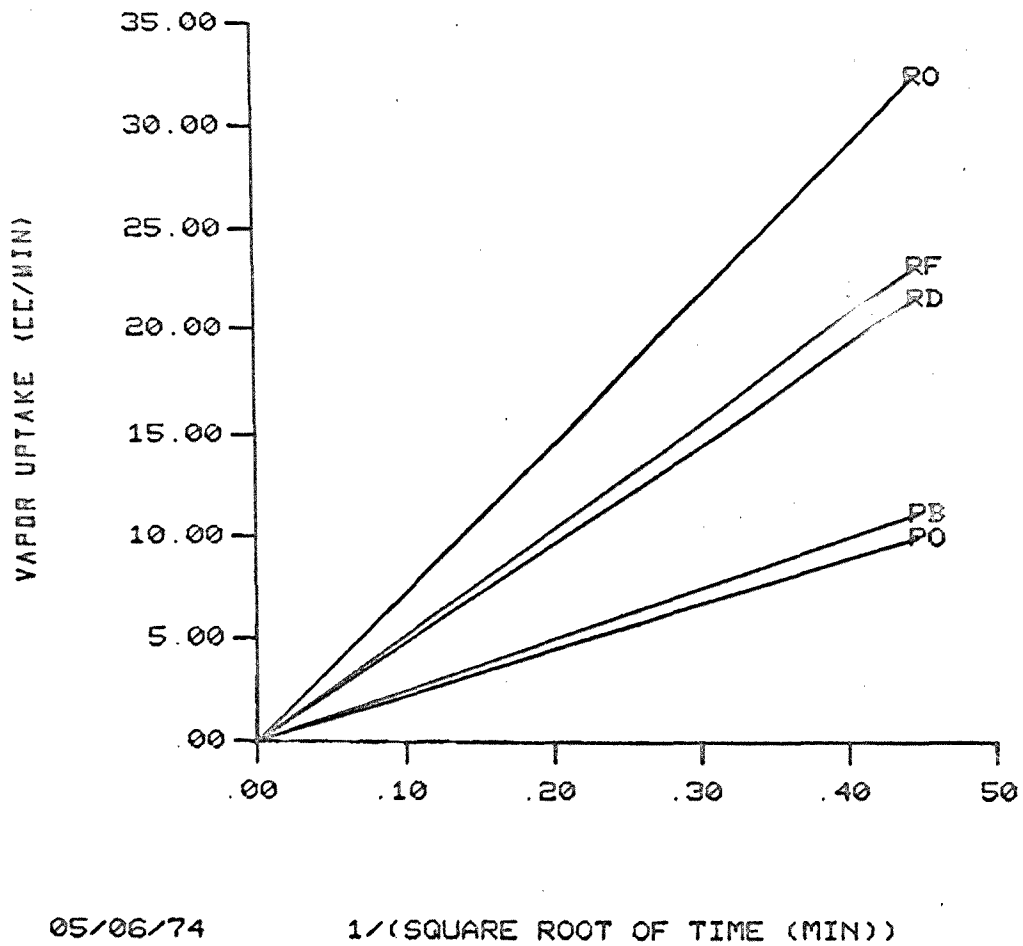
FIGURE NO. 42

VAPOR UPTAKE RATE 1% 2LPM
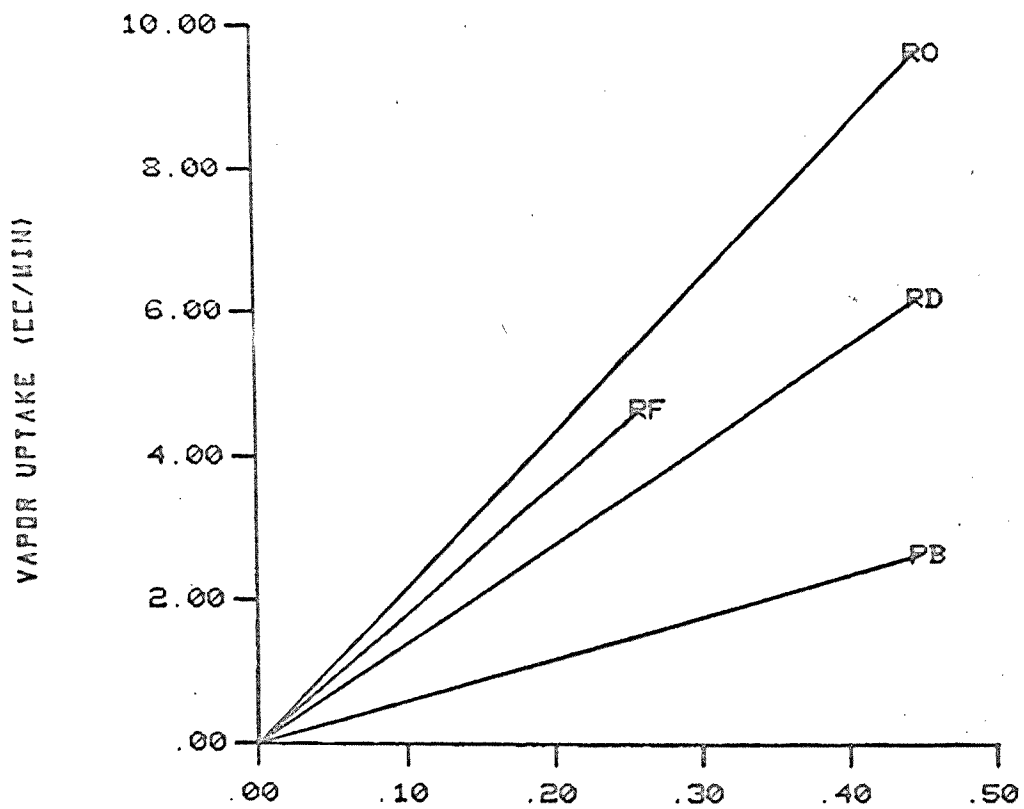
05/06/74   1/(SQUARE ROOT OF TIME (MIN))

Table #3 – Calculation of Diffusion Coefficients $(D\lambda^2)$

Ref: Figures 41 and 42

Equation No. 9

Material	Manufacturer	2% 2 LPM		1% 2 LPM	
		Slope	$D\lambda^2$	Slope	$D\lambda^2$
Rubber	Ohio (RO)	72.3	92.9	24.5	32.0
	Foregger (RF)	51.6	38.2	17.9	18.2
	Dupaco (RD)	48	76.9	13.7	24.5
Polyethylene	Bard–Parker (PB)	24.8	8.8	5.8	1.9
	Ohio (PO)	22.3	14.8	----	----

FIGURE NO. 43

$D \lambda^2 C$ vs Concentration
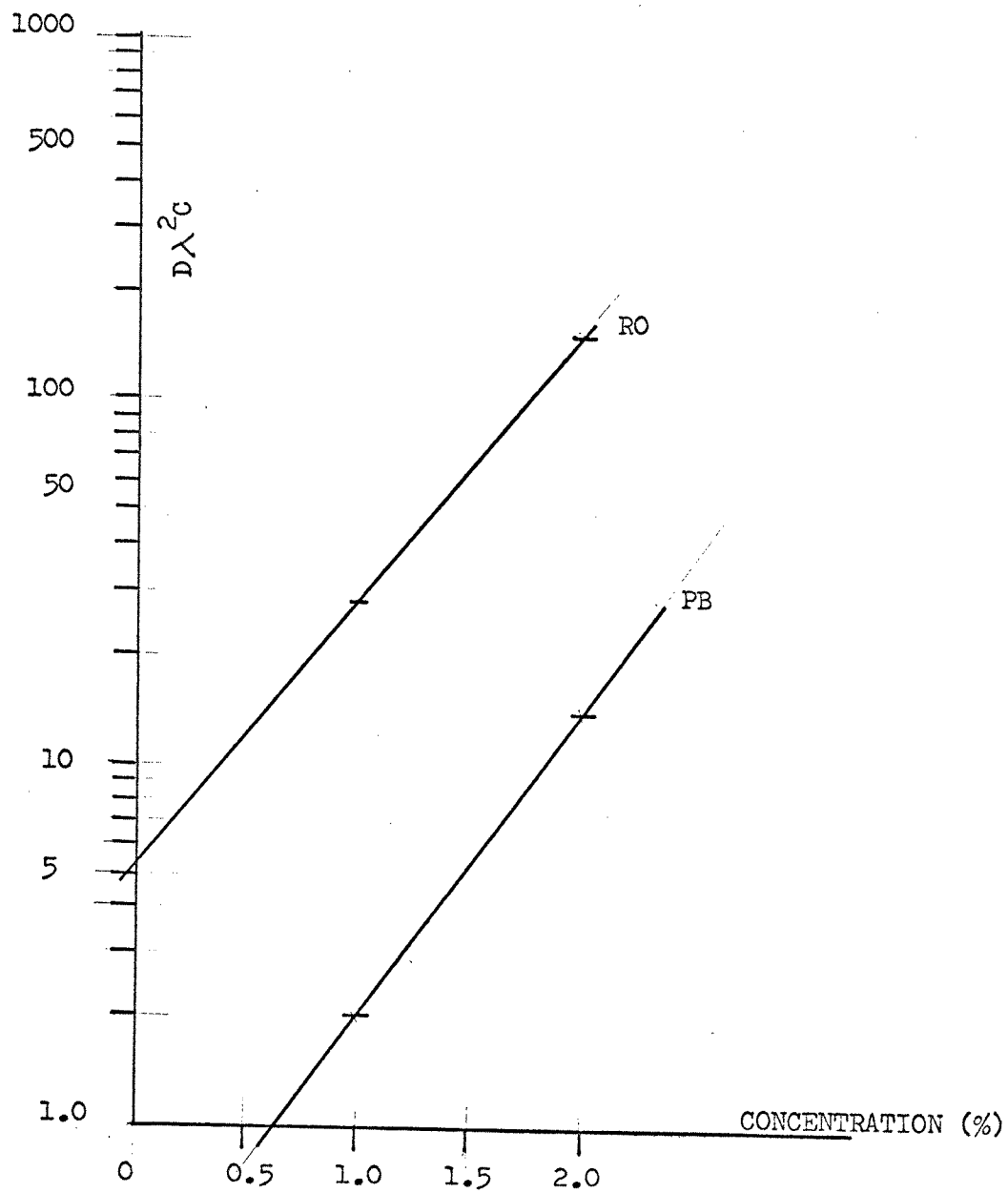
Table #4 - Calculation of the Factor I

Ref: Figures 6 and 43

Ohio Rubber

C	D/D_o	$I/D_o C_o$	I	$\log 10^I$
0.5	4.7	3.8	9.7	.987
1.0	5.0	4.0	20.4	1.310
1.5	8.6	6.0	45.9	1.662
2.0	14.8	10.0	102.0	2.009

$$d\log 10^I/dC_o = 0.68$$

Bard-Parker Polyethylene

C	D/D_o	$I/D_o C_o$	I	$\log 10^I$
1.0	6.7	4.8	1.4	.146
1.5	12.2	8.0	3.6	.556
2.0	23.3	15.0	9.0	.954

$$d\log 10^I/dC_o = .808$$

FIGURE NO. 44 THEORETICAL DIFFUSION
COEFFICIENTS
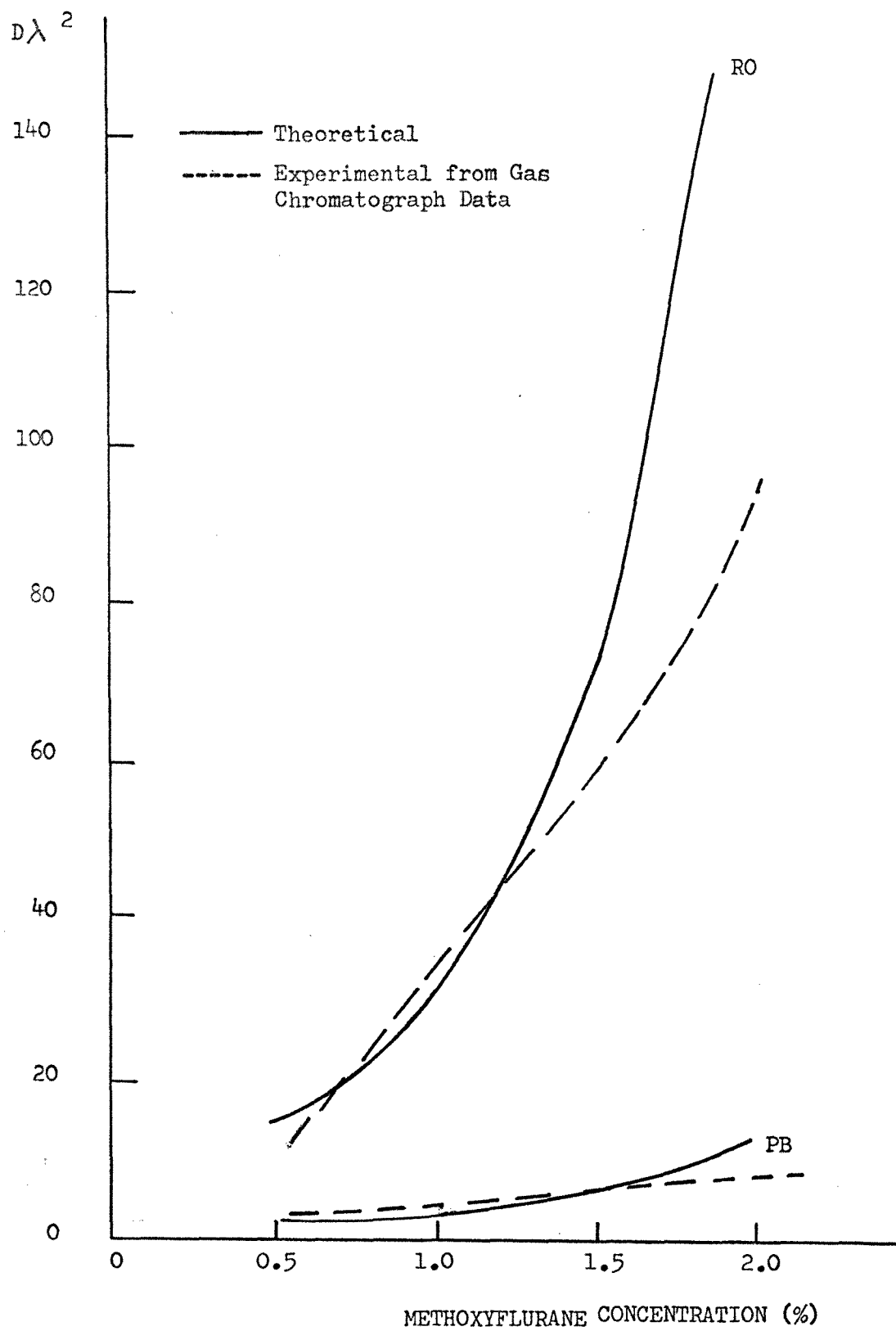
Chapter 9

RECOMMENDATIONS AND CRITICAL EVALUATION

The data obtained in this study was limited by the availability
of materials and time. Additional data for the diffusion of the hose
materials in question along with a selection of non conductive materials
is recommended. The study should also be extended to include some
of the other common vapor phase anesthetics such as Halothane (for
which a great deal of information is presently available) and Ethrane
(a recently developed anesthetic).

An interesting extension of the methods used herein would be
calculation of diffusion coefficients from infinite absorption time
data as well as time lag methods.

Use of gas chromatographic data appears to be more accurate than
weight gain methods since losses due to evaporation do not come into
play. The data obtained should be extended to include a wider range
of system concentrations and flow rates.

Lack of sufficient information regarding partition coefficients
as well as the effect of adsorption by the carbon filler prevented
a complete understanding of the mechanisms taking place.

Precise calibration of the anesthetic vaporizer was hampered by the variations experienced in temperature. This prevented accurate control of vaporizer output. It is recommended that future experiments attempt to control atmospheric and oxygen temperatures more accurately.

Chapter 10

CONCLUSIONS

It has been demonstrated that anesthetic absorption in conductive anesthetic hose and the resultant decrease in inspired concentration in the initial phases of administration is a function of the following parameters:

1 - Anesthetic concentration: As the concentration within the hose increases, the rate of diffusion increases. It has been shown that diffusion coefficients are inversely proportional to concentration. Thus, the assumption that each anesthetic/hose system has a constant diffusion coefficient is incorrect. Further studies should therefore be performed to develop a relationship between methoxyflurane and each hose material. This will help the user compute the anesthetic requirements for his specific system (hose, concentration, anesthetic and flow rate).

2 - Anesthetic hose material: It has been shown that conductive polyethylene hose absorbs significantly less methoxyflurane than conductive rubber. Use of conductive polyethylene will dramatically reduce anesthetic losses during induction rendering control more accurate. In addition, desorption from conductive polyethylene hose is less pronounced than

from conductive rubber, thus, minimizing the chance of
prolonged anesthesia and allergic reaction when the hose
is reused for a subsequent case.

3 - Oxygen flow rate: An increase in flow rate reduces
residence time thus reducing the effect of absorption.
Although the same quantity of anesthetic is absorbed by
the hose, more anesthetic passes through the hose and the
inspired concentration more closely approaches the vaporizer
output. Although losses are the same, the induction period
is shortened since the patient receives more anesthetic
over a shorter period of time. Likewise, increased flow
rate decreases the concentration of desorbed anesthetic thus
expediting recovery from anesthesia. However, since desorption
is a diffusion controlled process increasing flow rate cannot
significantly reduce the amount of anesthetic in the hose.
Therefore, the effect of reuse remaines a very real problem.

4 - Hose density: When rubber hose is used, density seems to have
an inverse effect on diffusion.

From the above conclusions it is recommended that the anesthe-
siologist consider use of conductive polyethylene hose as a replace-
ment for conductive rubber. In addition, the hose should be disposed
of after each case to prevent adverse reaction to unwanted anesthetic.
If rubber hose must be used, it is recommended that a high density
brand be chosen to minimize the effects of diffusion.

If at all possible, non conductive polyethylene should be chosen over its conductive counterpart since this material almost completely eliminates the phenomenon discussed above.

Gas chromatography has been found to be an effective method for measurement of anesthetic absorption effects. However, it is recommended that flame ionization detection be chosen if possible. Unlike the thermal conductivity method used in this study, flame ionization is insensitive to oxygen and will therefore permit more frequent sampling since it will not be necessary to wait for the oxygen peak prior to resampling. In addition, the flame ionization method is more sensitive and will permit more accurate measurement of quantities of desorbed anesthetic.

It is recommended that further studies be performed to develop the same relationships for other anesthetics such as Halothane, Ethrane and ether. This information would be invaluable to anesthesiologists.

The experimental method used herein for evaluating the various anesthetic hose materials could and should be applied to any new/ potential materials before consideration for field use.

REFERENCES

1. Abbot Laboratories Sales Literature, _A Guide to the Administration of Penthrane (Methoxyflurane)_, North Chicago, Ill., 1967.

2. Barrer, R. M., "Permeation, Diffusion and Solution of Gases in Organic Polymers," _Trans. Faraday Soc._, vol. 35, 1939, p. 628.

3. Barrer, R. M., "Some Properties of Diffusion Coefficients in Polymers," _J. Phys. Chem._, vol. 16, 1957, p. 178.

4. Crank, J. and Park, G., _Diffusion in Polymers_, Academic Press, London and New York, 1968.

5. Crank, J., _The Mathematics of Diffusion_, Oxford at the Clarendon Press, 1956.

6. Cullen, S. C., _Anesthesia_, Year Book Medical Publishers Inc., Sixth Edition, Chicago, Ill., 1961.

7. Eger, E. I., Larson, C. P., and Severinghaus, J. W., "The Solubility of Halothane in Rubber, Soda Lime and Various Plastics," _Anesthesiology_, vol. 23, no. 3, 1962, p. 356.

8. Eger, E. I. II M.D., and Brandstster, B, "Solubility of Methoxyflurane in Rubber," _Anesthesiology_, vol. 24, no. 5, 1963, p. 679.

9. Elam, J. O. and Lowe, H. J., "Studies on Anesthesia, Respiration and Resuscitation," Supported by U. S. Army R & D Command, Washington, D. C., Contract No. DADA-MD-17-67-C-7052, 1968-9.

10. Galla, S. J. and Ottenstein, D. M., "Measurement of Inert Gases in the Blood by Gas Chromatography," _Annals. of_ New York Acad. of Science, vol. 102, 1962, p. 4.

11. Galloon, S., "The Concentration of Anesthetics in Closed Circuits with Special Reference to Halothane - II Laboratory and Theatre Investigations," _Brit. J. Anaesth._, vol. 32, 1960, p. 310.

12. Larson, C. P., Eger, E. I., and Severinghaus, J. W., "The Solubility of Halothane in Blood and Tissue Homogenates," _Anesthesiology_, vol. 23, 1962, p. 349.

13. Littlewood, A., _Gas Chromatography Principles, Techniques and Applications_, Academic Press, New York and London, 1962.

14. Lowe, H. J., M.D., <u>Dose Regulated Penthrane (Methoxyflurane)</u> <u>Anesthesia</u>, Abbott Laboratories Technical Monograph, 1972.

15. Lowe, H. J. and Hagler, K., <u>Determination of Volatile Organic</u> <u>Anaesthetics in Blood, Gases, Tissues and Lipids: Partition</u> <u>Coefficients</u>, Ciba Foundation Symposium on Gas Chromatography in Biology and Medicine, 1969, pp. 86 - 103.

16. Lowe, H. J., "Flame Ionization Detection of Volatile Organic Anesthetics in Blood, Gases and Tissues," <u>Anesthesiology</u>, vol. 25, no. 6, 1964.

17. Lowe, H. J., Titel, J. H., and Hagler, "Absorption of Anesthetics by Conductive Rubber in Breathing Circuits," <u>Anesthesiology</u>, vol. 34, no. 3, 1971, p. 283.

18. Macintosh, Sir R., Mushin, W., Epstein, H., <u>Physics for the</u> <u>Anesthetist</u>, F. A. Davis Co., Third Edition, Philadelphia, Pa., 1970.

19. Michaels, A. S., and Bixler, H. J., "Flow of Gases Through Poly-ethylene," <u>J. Pol. Sci.</u>, vol. L, 1961, p. 413.

20. Park, G. S., "The Diffusion of some Halo-Methanes in Polystyrene," <u>Trans. Faraday Soc.</u>, vol. 46, 1950, p. 684.

21. Richman, D., and Long, F. A., "Measurement of Concentration Gradients for Diffusion of Vapors in Polymers," <u>J. Am. Chem. Soc.</u>, vol. 82, no. 3, 1960, p. 509.

22. Samulska, H. M., Bamaiah, S., Noble, W. H., "Unintended Exposure to Halothane in Surgical Patients: Halothane Washout Studies," <u>Canad. Anaesth. Soc. J.</u>, vol. 19, no. 1, 1972, p. 35.

23. Tilel, J. H. and Lowe, H. J., "Rubber Gas Partition Coefficients," <u>Anesthesiology</u>, vol. 29, no. 6, 1968, p. 1215.

24. Titel, J. H., Lowe, H. J., Elam, J. O., and Grosholz, J. R., "Quantitative Closed Circuit Halothane Anesthesia," <u>Anesthesia</u> <u>and Analgesia</u>, vol. 47, no. 5, 1968.