INFRARED ANALYSIS FOR CARBON DIOXIDE IN RESPIRED GASES CONTAINING CYCLOPROPANE AND ETHER

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THE INFRARED spectrophotometric method for the analysis of respired gases for carbon dioxide is in common use today. The presence of certain inhalational anesthetic agents has been shown to affect the estimation of carbon dioxide by such a method.[1-5] Ramwell[4] has shown that cyclopropane and nitrous oxide cause errors in analysis, while Bergman, Rackow and Frumin[5] have evaluated the response of an infrared carbon dioxide analyzer to the presence of nitrous oxide in a respiratory gas mixture. In this paper we shall present data on the effects of ethyl ether and cyclopropane on the infrared analysis for carbon dioxide.

METHODS

The instruments used in this study were two Liston-Becker model 16 Medical Carbon Dioxide Analyzers.[*] An microcatheter absorption cuvette (optical path length 0.1 inch) and a breathe-through absorption cuvette (optical path length 0.5 inch) were used. The detector cells were charged to a pressure of 50 mm. of mercury with carbon dioxide by the manufacturer and were not altered during this study. No other gases were present in the detector cells. The electrical output of the carbon dioxide analyzers was fed to suitable recorders. Carbon-oxygen mixtures chemically analyzed in an Orsat-type volumetric analyzer[†] were used to calibrate the instruments prior to each use.

Two procedures were used to determine the effect of cyclopropane on the infrared gas analyzer. In the first procedure, used only with the breathe-through cuvette, two 3-liter breathing bags with open "tails" were fastened to opposite ends of the cuvette on the pick-up head and were thoroughly flushed, and then filled with a known concentration of carbon dioxide in oxygen. The tails of the bags were clamped and the carbon dioxide content was noted on the previously calibrated meter scale. At this point a roughly measured amount of cyclopropane was admitted through the tail of one of the bags, the gas in the two bags mixed, and the reading on the meter-scale noted. A sample of the mixed gas was removed and analyzed for its cyclopropane content by absorption in 31 normal sulfuric acid in a Scholander "quick" gas analyzer.[6] The true carbon dioxide content was calculated from the original percentage of carbon dioxide and the dilution by cyclopropane.

The second procedure was used to determine the effect of cyclopropane and ether on both the breathe-through and microcatheter cuvettes. A chemically-analyzed cylinder of carbon dioxide in oxygen was connected to an anesthesia machine in place of the oxygen cylinder. The gas outlet of the anesthesia machine was connected to the breathe-through cuvette with rubber tubing or was vented to the atmosphere, a T-tube being connected to the suction catheter of the microcatheter cuvette. In some of the studies the breathe-through and microcatheter cuvettes were used simultaneously. Gas was drawn through the microcatheter cuvette at a constant rate of about 500 ml. per minute. To obtain the desired gas mixture, the carbon dioxide-oxygen mixture was flowed through the oxygen flow meter and cyclopropane was added through its flowmeter. The ether-carbon dioxide-oxygen mixtures were prepared similarly in a Foregger rotameter model anesthesia machine with a Copper Kettle ether vaporizer using the carbon dioxide-oxygen mixture to vaporize the ether. The total gas flow was always at least one liter/minute. When the desired gas mixture was flowing from the machine to the analyzer and a steady reading was obtained on the recorder, a 100 ml. gas sample was drawn

slowly into the buret on the Orsat gas analyzer after first flushing the connecting tubing and the analyzer. This gas sample was analyzed by absorbing the carbon dioxide in 54 per cent potassium hydroxide solution followed by absorption of ether or cyclopropane in concentrated (95 per cent) sulfuric acid. The slight solubility of cyclopropane or ether in the potassium hydroxide solution was repressed by equilibrating this absorbent with a separate sample of the gas prior to the actual analysis.

RESULTS

Cyclopropane. A total of 56 carbon dioxide-cyclopropane-oxygen mixtures were prepared and analyzed for carbon dioxide by infrared absorption and chemically for cyclopropane and carbon dioxide. Forty-six of these mixtures were analyzed in the breathe-through cuvette and 10 in the microcatheter cuvette. The concentrations of carbon dioxide ranged from 3 to 18 volumes per cent, and those of cyclopropane from 5 to 54 volumes per cent. Cyclopropane concentrations were varied at each carbon dioxide level. The infrared analyses were in error from 0 to $+1.3$ volumes per cent, the larger errors being associated with the higher cyclopropane and carbon dioxide concentrations. There was no apparent difference in the error in the infrared analyses with the different instruments or techniques.

Since it appeared from the data that the error was related to the proportion both of carbon dioxide and of cyclopropane in the mixture, a graphic function was sought which
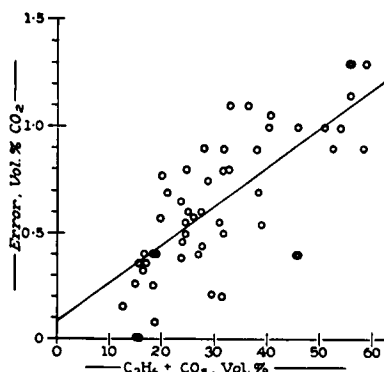

FIG. 1. Error in infrared carbon dioxide analyses in relation to the composition of the gas mixture (see text).
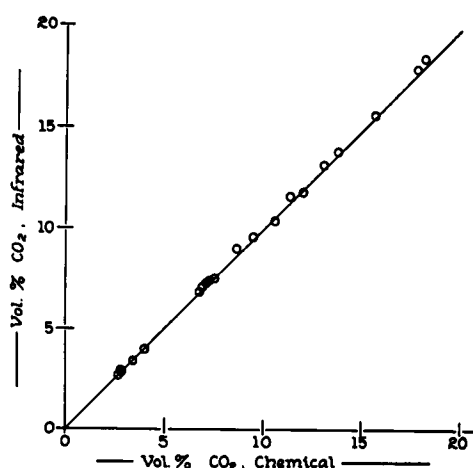

FIG. 2. Comparison of infrared and chemical analyses for carbon dioxide in the presence of ether vapor.

would take these two factors into consideration. The best correlation appeared (by inspection) to be given by the sum of the volumes per cent of cyclopropane plus the volumes per cent carbon dioxide (infrared) plotted against the difference, in volumes per cent, between the observed infrared carbon dioxide and the chemical carbon dioxide. Figure 1 presents the data obtained from the 56 analyses with a least-squares regression line. The regression coefficient is $+0.72$. With the aid of figure 1, one may estimate the error in carbon dioxide analysis that might occur during cyclopropane anesthesia. For example, at 10–20 volumes per cent cyclopropane with normal pCO_2, the error in pCO_2 would be about 3 mm. of mercury. At a pCO_2 of 70 mm., the error would increase to about 4 mm. of mercury. In the usual clinical range, therefore, one would expect an error of less than 5 mm. even with moderate degrees of hypercarbia.

Ether. Twenty ether-oxygen-carbon dioxide mixtures were prepared and analyzed by infrared absorption for carbon dioxide and chemically for carbon dioxide and ether. Twelve of these mixtures were analyzed in the breathe-through cuvette and eight in the microcatheter cuvette. The concentrations of carbon dioxide ranged from 3 to 18 volumes per cent and those of ether vapor from 1 to 27 volumes per cent. The ether concentration

was varied at each carbon dioxide level. The infrared error in this series ranged from -0.2 to $+0.5$ volumes per cent carbon dioxide and did not appear to be related to the ether concentration. A least-squares correlation coefficient for volumes per cent ether *vs.* error (infrared carbon dioxide minus chemical carbon dioxide) is $+0.02$, an insignificant value. A plot of ether concentration *vs.* error is a scatter with most (16 of 20) of the points representing positive error, thus indicating a slight tendency toward high infrared values for carbon dioxide in the presence of ether. In figure 2 the infrared carbon dioxide concentration is plotted against the chemically-analyzed concentrations. The line in figure 2 is the theoretical line for perfect agreement between infrared and chemical analysis for carbon dioxide.

DISCUSSION

Infrared gas analyzers of the positive filtering type (e.g. the Liston-Becker CO_2 analyzer) use a detector cell that contains the same gas as that to be determined. The cell thus detects infrared radiation only at the wave lengths of the absorption bands of the gas which fills it. As radiation is absorbed by the detector cell, its contents are heated and the pressure in the cell is increased. This pressure increase is converted to an electrical signal by a variable capacitor. The gas sample to be analyzed, in passing through the cuvette, absorbs some infrared radition, thus leaving less to impinge on the detector cell. If the composition of the gas mixtures used for calibration of the infrared analyzer is the same as that of the sample mixture, the analyzer will indicate the true carbon dioxide content of the sample. Even in the absence of other absorbing gases, however, the analysis may be incorrect if the calibration has been performed with a gas mixture whose composition varies greatly from that of the sample mixture. This effect, which is due to a phenomenon known as "collision broadening" or "pressure broadening," results from the collision of absorbing molecules with nonabsorbing molecules.[1] Collision, broadening, which occurs to some extent in all gas mixtures, increases the amount of radiation absorbed over that which would be absorbed by the gas alone at its given partial

pressure. The degree of increase in absorption depends on the specific gas mixture. Bergman, Rackow and Frumin[5] have pointed out that collision broadening of infrared spectra affects the side bands rather than the central portion of the absorption band. They have shown further that absorption by the side bands can be reduced by lowering the pressure of the absorbing gas in the detector cell. In this manner, errors due to collision broadening can be minimized.

A second possible source of error in infrared gas analysis may result from the presence of other gases whose absorption bands overlap those of the gas being measured. This type of error is of minor importance for carbon dioxide analysis in the presence of cyclopropane or ether since they have only slight absorption at 2.6 and 4.3 microns, the principal absorption bands of carbon dioxide.[7] Since pure cyclopropane does not cause infrared analyzers to indicate the apparent presence of carbon dioxide,[8] the errors in this study are probably due to collision broadening of the absorption bands of carbon dioxide.

The scatter of the data in figure 1 may be attributed, in part, to error in the infrared analyses for carbon dioxide and to errors in the chemical analyses. Error in the infrared analyses is large at higher carbon dioxide percentages due to decreased sensitivity of the instrumental response at these higher values. This was especially true in the microcatheter cuvette which was designed to be used with lower percentages (0–9 per cent) of carbon dioxide. The scatter of the data may also be attributed, in part, to the collision broadening effect itself which probably cannot be related to the partial pressures of the gases by this simple mathematical function. The relative simplicity of figure 1, however, is desirable for use in correcting errors in observed carbon dioxide concentrations. No other simple function (product, quotient, or logarithm) of the concentrations of cyclopropane and carbon dioxide gave a better correlation when plotted against the error in the infrared analysis or the per cent error. Neither did cyclopropane or carbon dioxide concentrations alone correlate as well with error.

In contrast to cyclopropane, ether vapor in anesthetic concentrations did not appear to in-

fluence infrared analyses for carbon dioxide. The difference in the effect of the two agents on the infrared absorption of carbon dioxide is indicative of the complex nature of the collision broadening phenomenon which depends not only on the partial pressures of the gases involved but also on the specific kinds of gas molecules.

SUMMARY

Cyclopropane, when present in anesthetic concentrations, increases the apparent concentration of carbon dioxide indicated by infrared carbon dioxide analyzers. Ether vapor does not appear to influence infrared carbon dioxide analyses. The magnitude of the error caused by cyclopropane can be related to the total amount of cyclopropane and carbon dioxide present in the gas mixture. This effect is probably due to the collision broadening of the carbon dioxide absorption bands. The effect was approximately the same in two instruments.

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