

## CORRECTION FACTORS FOR INFRARED CARBON DIOXIDE PRESSURE BROADENING BY NITROGEN, NITROUS OXIDE AND CYCLOPROPANE

J. W. SEVERINGHAUS, M.D., C. P. LARSON, M.D., E. I. EGER, M.D.

PRESSURE (or collision) broadening introduces errors in infrared analysis of  $\text{CO}_2$  when nitrogen, nitrous oxide or cyclopropane are present in the sample but not in the calibrating gas. Correction for this error requires the use of accurately known mixtures of  $\text{CO}_2$  in these gases. In previous reports on pressure broadening<sup>1-6</sup> workers have utilized either chemical analysis or volumetric mixing methods. Chemical analysis of  $\text{CO}_2$  in anesthetic gases is somewhat difficult due to absorption of the anesthetic into the  $\text{CO}_2$  absorber. The  $\text{CO}_2$  electrode,<sup>7</sup> being unaffected by anesthetics, permits greater accuracy and speed in preparing correction factors for this effect. Since the relatively new Beckman-SpincO LB-1  $\text{CO}_2$  analyzer has not been studied in the published reports, it seemed wise to draw attention to its considerably reduced broadening effect in comparison with older instruments.

We also wish to introduce a simple method of correcting for the pressure broadening effect involving a constant multiplier for the apparent  $\text{CO}_2$  concentration given a constant background gas.

### METHOD

Two Beckman SpincO LB-1 infrared  $\text{CO}_2$  analyzers with microcatheter sampling cells were used. The detector cells were charged with  $\text{CO}_2$  to a pressure of 50 mm. of mercury. The analyzer heads were flushed and filled with  $\text{N}_2\text{O}$  under slight positive pressure to eliminate the error due to the overlapping absorption bands of  $\text{N}_2\text{O}$  and  $\text{CO}_2$ . Regulated negative pressure of -100 mm. of mercury was applied to the sample cell outlet. Flow through the cell was controlled to 5-10 ml./second by an orifice at the sampling tip. Most of this 100 mm. pressure drop occurred at the inlet orifice, so pressure in the sample

cell approximated -100 mm. of mercury. In end-tidal sampling, this modification reduces the effect of pressure fluctuations in the airway, eliminates condensation of water vapor in the sampling catheter, and improves response time. The use of low pressure in the sample cell also increases linearity.<sup>8</sup> Readings were obtained directly from the meter on the amplifier in order to eliminate possible errors arising in further amplification and direct writing instruments. Full scale sensitivity was approximately 10 per cent  $\text{CO}_2$  in  $\text{O}_2$ .

Calibration gases ( $\text{CO}_2$  in air and  $\text{CO}_2$  in  $\text{O}_2$ ) in cylinders were analyzed chemically (Scholander 0.5 ml.) and redetermined against each other on the  $\text{CO}_2$  electrode. Response curves for  $\text{CO}_2$  in air and  $\text{CO}_2$  in  $\text{O}_2$  were then prepared.

Anesthetic test mixtures and additional  $\text{CO}_2$  in air or  $\text{O}_2$  mixtures were prepared volumetrically in a 1,500 ml. plastic syringe. After mixing, they were analyzed simultaneously in the electrode and infrared analyzer. The infrared analyzer sampling was from an open ended rubber tubing through which the syringe was slowly emptied, producing a flowing stream of gas at atmospheric pressure.

A number of the anesthetic mixtures were analyzed both in the electrode and in duplicate with the Scholander technique, using a correction for anesthetic gas solution described in a previous publication.<sup>8</sup>

The  $\text{CO}_2$  electrode (National Welding Co.) was mounted in a 37 C water bath. The output was read on an Instrumentation Laboratory blood gas analyzer with a Tapot readout calibrated logarithmically from 1.0 to 100 per cent (or 10 to 1,000 mm.  $\text{P}_{\text{CO}_2}$ ) having 1,000 divisions over the range. Readings over the entire range could be read to 0.5 per cent of the value (not of full scale). That is, 2 per cent  $\text{CO}_2$  could be read to  $2.00 \pm .01$  per cent. Drift of the entire system was less than 1 per cent in 8 hours, *i.e.*, 0.05 per cent  $\text{CO}_2$  at 5 per cent  $\text{CO}_2$ . Reproducibility and linearity

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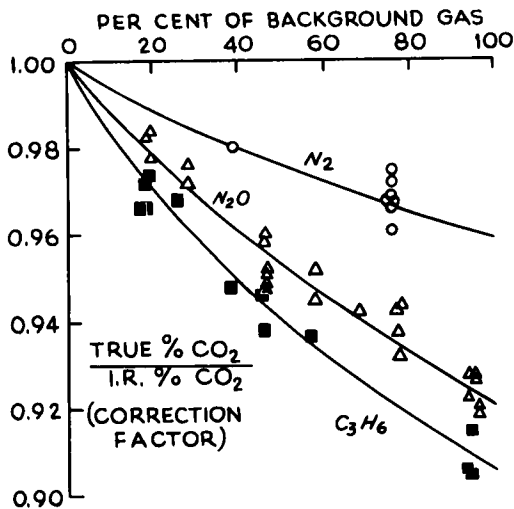


FIG. 1. "True % CO<sub>2</sub>" is the value obtained from CO<sub>2</sub> electrode analysis, supplemented in some instances by Scholander analysis. "IR % CO<sub>2</sub>" is the value obtained from a calibration curve plotting meter deflection against CO<sub>2</sub> in oxygen. The ratio of these readings when background gases other than oxygen are present is a correction factor. The IR percentage CO<sub>2</sub> multiplied by the correction factor gives the true percentage CO<sub>2</sub>.

were both better than 0.5 per cent. Response time was about two minutes.

The electrode membrane was 0.001 inch Teflon. Instead of the usual cellophane, 8 denier nylon stocking mesh was used to hold the 0.01M NaHCO<sub>3</sub> and saturated KCl electrolyte layer. With this modification, the electrode is linear down to 0.5 per cent CO<sub>2</sub>. The electrode cuvette was kept wet to insure that the gas samples would be saturated at 37 C. Readings were made with gas stationary in the cuvette, to avoid cooling and drying effects.

#### CALCULATION

Readings from the microammeter on the infrared analyzer amplifier were converted to percentage CO<sub>2</sub> from a CO<sub>2</sub> in O<sub>2</sub> calibration curve. All readings were considered as dry gas readings. The dilution effect of water vapor has been shown<sup>2, 8</sup> to be almost counterbalanced by a presumed pressure broadening effect of water vapor. The remaining effect of water vapor is "ironed out" by the tendency of water vapor to cling to sample cell walls. The electrode scale readings were also read as percentage dry gas. (Since both

calibration gas and test gas are saturated at the same temperatures in the electrode cuvette, the reading is independent of the water vapor in the sample just as it is in the Scholander apparatus.)

#### RESULTS

We computed the ratio of the correct concentration (from Scholander and CO<sub>2</sub> electrode) to the concentration value obtained from the infrared analyzer using a CO<sub>2</sub> in O<sub>2</sub> calibration curve. This ratio is a correction factor, and is plotted in figure 1 as a function of N<sub>2</sub>, N<sub>2</sub>O and cyclopropane concentration. The factor for CO<sub>2</sub> in O<sub>2</sub> is 1.0.

There was no detectable variation of the correction factor over the range of 1.5–9 per cent CO<sub>2</sub>. The two instruments appeared to have identical broadening effects.

Varying the total pressure in the sample cell has an effect on pressure broadening. Figure 2 presents data on 95 per cent N<sub>2</sub>O and 5 per cent CO<sub>2</sub>. The effect is relatively unimportant if sample cell pressure is within 100 mm. of mercury of atmospheric pressure.

#### DISCUSSION

Several workers<sup>3, 5</sup> have noted that the error in percentage CO<sub>2</sub> incurred by pressure broadening, is proportional to the CO<sub>2</sub> concentration. If this is true, then the ratio of true CO<sub>2</sub> to the apparent CO<sub>2</sub> (based on a CO<sub>2</sub> in O<sub>2</sub> calibra-

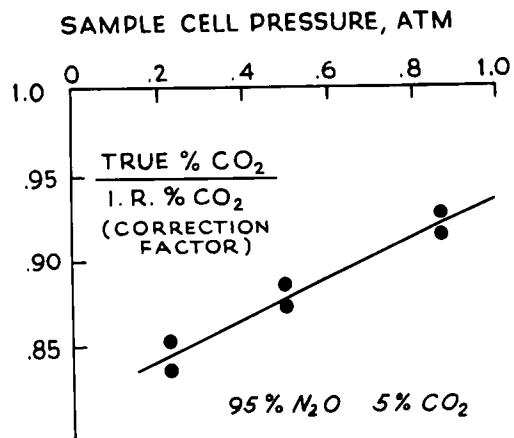


FIG. 2. The pressure broadening effect increases as the total pressure in sample cell is reduced. The effect is negligible at usual sampling pressures of 0.87 to 1.0 atmosphere. (– 100 mm. of mercury to zero negative pressure).

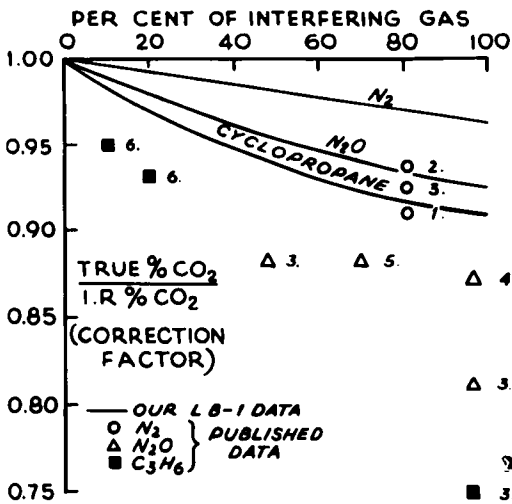


FIG. 3. Correction ratios computed from published data compared with the present study. Liston Becker Model 16 was used by Collier,<sup>2</sup> Bergman<sup>4</sup> and Linde.<sup>6</sup> Infrared Development Co. meter was used by Ramwell<sup>3</sup> and Cooper.<sup>5</sup> Stow<sup>1</sup> constructed his own instrument.

tion curve) would be independent of CO<sub>2</sub> concentration. Our data support the constancy of this ratio. This is also in accord with the theoretical basis for pressure broadening as described by Lorenz.<sup>9</sup> Therefore, this ratio may be used as a correction factor for readings taken from a CO<sub>2</sub> in O<sub>2</sub> calibration curve. This also makes it unnecessary to prepare separate calibration curves for mixtures containing the anesthetic gas.

The most important observation made in this study is that the pressure broadening in the Beckman Spinco LB-1 analyzer is less than half that reported by previous investigators using the Liston Becker Co. and the Infrared Development Co. (English) CO<sub>2</sub> analyzers. The correction ratios which we have calculated from published data are plotted in comparison with our data in figure 3. Ramwell gives values for N<sub>2</sub>, N<sub>2</sub>O and cyclopropane which all show about 2.5 times the broadening effect that we obtained, but bear about the same relationship to each other that our data do; that is, N<sub>2</sub>O has twice the broadening effect of N<sub>2</sub> and cyclopropane has about 25 per cent more effect than N<sub>2</sub>O. This suggests that while there are consistent differences between instruments, the relative effects of these gases on CO<sub>2</sub> may be the same in all instruments.

Further evidence that the Beckman Spinco instrument is less subject to pressure broadening than other instruments is found by recalculation of Linde and Lurie's data<sup>6</sup> (fig. 4), for cyclopropane. The original data<sup>6</sup> obtained by Linde and Lurie on the pressure broadening of cyclopropane in a Liston Becker Model 16 analyzer have been plotted in figure 3 and compared to our results with cyclopropane. It is evident that their analyzer had a larger broadening effect than the Beckman-Spinco LB-1 used in this investigation. The ratio appears to be independent of CO<sub>2</sub> concentration which in their data ranged from 3-18 per cent.

These findings suggest that the design of the infrared detector has some effect on the magnitude of pressure broadening. Bergman *et al.*<sup>4</sup> have suggested a dependence on the detector cell CO<sub>2</sub> pressure. However, the detectors in the instruments used by Linde and Lurie<sup>6</sup> and by Ramwell<sup>3</sup> were all charged with 50 mm. of mercury P<sub>CO<sub>2</sub></sub> as were ours. This then cannot account for the difference. Variation of sample cell pressure appears to alter the correction ratio for pressure broadening, but none of the previous workers used as low a pressure in the cell as we did. By extrapolation to atmospheric pressure (fig. 2) the correction factor for CO<sub>2</sub> in N<sub>2</sub>O would

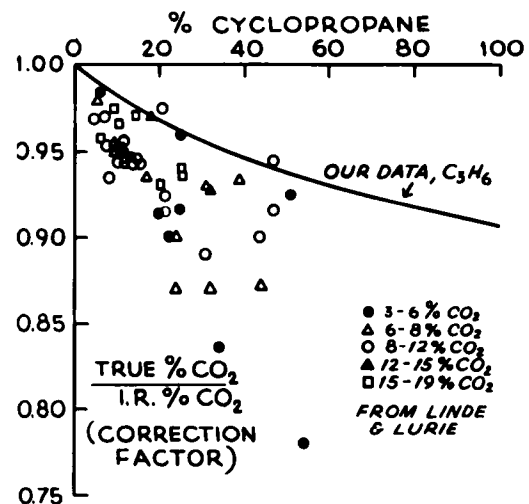


FIG. 4. Data supplied by Dr. Linde for cyclopropane show no correlation of the correction ratio with percentage CO<sub>2</sub>.

◦ Kindly supplied by Dr. Linde.

be 0.94 in our instrument. Linde and Lurie found no difference between analyzers with optical path lengths in the sample cuvette of 0.1 inch and 0.5 inch although the scatter is too great to rule out such an effect. Ramwell's data agree with ours on the relative magnitude of the effect of the three gases,  $N_2$ ,  $N_2O$  and cyclopropane. This relationship probably is transferrable to other instruments. This would suggest that other instruments could be checked at one point, for example 5 per cent  $CO_2$  in 95 per cent  $N_2O$  as compared with a  $CO_2$  in  $O_2$  calibration curve and the remainder of the correction factors computed from our data. For example, if an instrument showed a ratio of 0.90 for 95 per cent  $N_2O$ , a set of curves could be prepared from our data by multiplying appropriate ratios from our curves by the ratio 0.90/0.92, 0.92 being our ratio for 95 per cent  $N_2O$ .

This approach indicates that previously obtained data can be corrected in retrospect (provided the anesthetic concentration is known).

#### SUMMARY

The pressure broadening effect of  $N_2$ ,  $N_2O$  and cyclopropane on two Beckman Spinco LB-1 infrared  $CO_2$  analyzers with microcatheter sampling cells has been checked by using the  $CO_2$  electrode which is unaffected by anesthetic gases. The LB-1 analyzer exhibits less than half the effect reported in other instruments. The  $CO_2$  concentration value derived from infrared analyzer readings, with a  $CO_2$  in  $O_2$  calibration curve, may be corrected for the error due to these gases by multiplying the value by a factor depending on background gas concentration and sample cell pressure. This factor is inde-

pendent of  $CO_2$  concentration from 1.5 to 9 per cent and probably to 18 per cent  $CO_2$ . The correction factors in the LB-1 analyzer were found to be 0.97 for air, 0.94 for 70 per cent  $N_2O$  and 0.97 for 20 per cent cyclopropane. The relative broadening effect of these three gases is probably the same in other instruments but the absolute factor varies for unknown reasons related to detector head design. The  $CO_2$  electrode is useful for analysis of  $CO_2$  in anesthetic gases, since it is unaffected by such gases.

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