THE DRÄGER CARBON DIOXIDE ANALYZER

BY

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There has long been a need for a simple and portable carbon dioxide analyzer suitable for use in the operating theatre or at the bedside. The analyzer to be described* appeared to fulfill many of the requirements, and we have therefore made a critical study of its performance with special reference to its use during anaesthesia. No details of its performance have yet been published but Scurr (1956) has reported its use during anaesthesia.

DESCRIPTION

The analyzer was devised during the last war for use in submarines. It is in the form of a perspex cylinder 5 cm in diameter and 20 cm in length. The lower part rotates on the top part, thereby operating the taps which direct the gas into the various parts of the apparatus.

The analyzer is shown diagramatically in figure 1. Gas is drawn directly into the sampling cylinder by the piston, whose stroke is limited by an adjustable stop. This samples a predetermined volume (approximately 10 ml) which is repeatable within very narrow limits. The gas is then passed into the absorption chamber containing 25 per cent sodium hydroxide. Carbon dioxide in the sample is rapidly absorbed and a volume of alkali, approximating to the residual gas volume, is forced into the measuring cylinder which is graduated to indicate the percentage of the sample which has been absorbed. In figure 1 the analysis is completed and the alkali is partly displaced into the measuring cylinder. The piston stop is previously adjusted to give a zero reading during a blank analysis of gas which contains no carbon dioxide.

SOURCES OF ERROR

The gas analyzers of Haldane (1920) and Scholander (1947) have been carefully designed to ensure that all measurements of gas volumes are made under the same conditions of temperature and pressure and with the gas in contact with liquids of the same vapour pressure. In the Dräger analyzer, however, the conditions before and after absorption of the carbon dioxide are different. Gas is drawn into the sampling cylinder (and thereby measured) at ambient temperature and pressure. Expired gas will be saturated with water vapour at ambient temperature. In the absorption chamber the vapour pressure of the alkali is some 10 mm Hg less than that of water at room temperature and the gas volume will be further reduced by the hydrostatic pressure of the column of alkali forced into the measuring cylinder—also of the order of 10 mm Hg. If these errors are constant, compensation is possible by adjustment of the piston stop.

* Manufactured by Drägerwerk, Lübeck.
There are various sources of random error of which by far the most important is differences in temperature between the sampling cylinder and absorption chamber. The apparatus should always be allowed sufficient time to assume the temperature of the room in which the analysis will take place. Regional heating by sunlight or proximity to radiators will introduce a serious error, but more insidious is the heat of the operator's hand.

The error due to changing ambient temperature. If regional heating is avoided, changing ambient temperature will affect both sampling cylinder and absorption chamber and there will be no resultant error from expansion of the gas. However, the vapour pressures of water ($P_{H_2O}$) and caustic soda ($P_{NaOH}$) will both vary with changing temperature. The volume of CO₂-free gas ($V$) on passing into the absorption chamber will become:

$$V = \frac{P_B - P_{H_2O}}{P_B - P_{NaOH}} \times V$$

where $P_B$ is the barometric pressure.

This factor will vary appreciably with changes in temperature, but not to any significant degree with changes in barometric pressure over the normal range.

The error due to the hydrostatic pressure of the column of sodium hydroxide in the measuring cylinder.

The volume of CO₂-free gas will be reduced on passing into the absorption chamber by a factor dependent upon the hydrostatic pressure of the sodium hydroxide. If the vertical height of the column is $h$ and the specific gravity of the liquid is $\rho$ the factor will be:

$$\frac{P_B}{P_B + h \times \rho}$$

The specific gravity of 25 per cent sodium hydroxide is 1.21 and the height of the column varies with the part of the scale reached by the alkali:

$$h = (16 - 0.45 \times S) \text{ cm}$$

where $S$ is the scale reading in percentage of CO₂.

Thus the factor for the hydrostatic pressure becomes:

$$\frac{P_B}{P_B + 1.21 (16 - 0.45 \times S)}$$

Changes in the barometric pressure within the normal range will not affect the factor appreciably. During a blank analysis with CO₂-free gas the piston stop may be adjusted by trial and error to correct for both the hydrostatic pressure and the temperature effect. Thereafter only changes in the ambient temperature or the strength of the alkali would necessitate resetting of the piston stop.

It is clearly not feasible to reset the piston stop to compensate for the different hydrostatic pressures obtained with different concentrations of CO₂ in the sampled gas. The error from this effect is, however, proportional to the concentration of CO₂ and allowance could be made—either as a correction factor or by an adjustment of the engraved scale.

A number of experiments were carried out to determine the magnitude of these errors in practice. In addition, an assessment was made of the error due to the presence of nitrous oxide in the diluent gas. This gas is freely soluble in dilute caustic soda and we therefore explored the use of saturated alkali, in which nitrous oxide is almost insoluble.

METHOD OF ASSESSMENT

The entire apparatus was kept at a constant temperature for at least one hour before use. The analyzer was held in a retort stand and handling was avoided as far as possible. All gases were sampled from a moist 100 ml syringe, in which they were allowed to become saturated with water vapour. No samples of dry gas were analyzed, as this would require resetting of the piston stop.

Zero adjustments were made by performing a blank analysis on air which had been freed of CO₂ with soda lime and saturated with water vapour. The piston stop was adjusted by trial and error until zero readings were obtained. Calibration was carried out against five cylinders of CO₂ in nitrogen which had been analyzed by the method of Haldane.

For the studies on the effect of nitrous oxide, mixtures of CO₂ were prepared in a diluent gas of 70 per cent nitrous oxide and 30 per cent oxygen. The CO₂ concentration in these mixtures was determined by the modification of the Haldane technique described by Prime (1950).

CO₂ concentrations were determined to within 0.1 per cent and errors are expressed as a percentage of the sampled volume.

RESULTS

Setting of the piston stop for the zero reading tended to be tedious and time consuming. The setting generally gave readings within 0.1 per cent of zero for 12 hours. Thereafter the reading tended to rise by 0.2 per cent per day—possibly as a result of the alkali taking up moisture.

The effect of ambient temperature on the zero setting was studied by adjusting the piston stop for CO₂-free gas at 25°C and repeating the observations after equilibration at 13°C and 32°C.
At the low temperature the values obtained varied from 0.2 to 0.4 per cent below zero and at the high temperature from 0.2 to 0.4 per cent above zero.

The calibration against Haldane's method is shown in figure 2. The solid line indicates one-to-one correspondence, while the broken line indicates the mean of five analyses on each gas cylinder. The random error at no time exceeded 0.1 per cent. The systematic error is proportional to the concentration of CO$_2$ in the sample and is 0.06 per cent high for each 1 per cent of CO$_2$ in the sample.

Dräger analysis of CO$_2$ in a diluent of nitrous oxide and oxygen gave a value which was much higher than the concentration determined by the Haldane method (fig. 3). Subsequent analyses gave lower values which approached the true value in a quasi-exponential manner, as the alkali approached saturation with nitrous oxide. Nevertheless even after seven analyses the error was still appreciable at almost 1 per cent.

Immediately after eight analyses with nitrous oxide present, a series was commenced with CO$_2$ dispersed in nitrogen. Nitrous oxide then came out of solution giving a reading less than the true value (fig. 3).

The analyzer was then filled with saturated caustic soda (72 per cent or 18 normal). A considerable re-adjustment of the piston stop was required as the vapour pressure of saturated soda is less than 1 mm Hg. Analysis with the con-
The results of a series of analyses of carbon dioxide dispersed in a nitrous oxide-oxygen mixture, followed by a second series of analyses of a mixture of carbon dioxide in nitrogen. The inset figures indicate the carbon dioxide concentration determined by the Haldane method. The results obtained by the Dräger method have been corrected according to the calibration curve (fig. 2).

Using the saturated alkali, six analyses were made on a mixture containing 4.79 per cent CO₂ dispersed in 70 per cent nitrous oxide and 30 per cent oxygen. The mean value obtained was 4.92 per cent (range 4.8–5.1) and this agrees closely with the calibration curve (fig. 2). Six analyses were then made on a mixture containing 9.14 per cent CO₂ in the same diluent gas. The mean value was 9.48 per cent (range 9.3–9.7) showing a deviation of 0.2 per cent from the calibration curve and a greater random error.

It was repeatedly found that when the apparatus was held in the hand, large errors became apparent and it was impossible to obtain agreement between duplicate analyses. Even with our precautions against local heating it was often found to be difficult to carry out correctly more than three analyses in succession.

CONCLUSIONS

It appears that the Dräger CO₂ analyzer has sufficient accuracy for clinical use. Its portability and ease of operation make it suitable for use in the operating theatre or at the bedside. Its apparent simplicity is, however, deceptive and attention to certain details is necessary if the results are to be of value.

Zero setting. It is advisable to check the setting of the piston stop each time the apparatus is used. This is particularly important if the ambient temperature is markedly different or if the alkali is changed.
Calibration error. Each apparatus should be checked against mixtures of known CO₂ concentrations and a note made of any significant systematic error. Calibration provides the operator with invaluable experience in the handling of the apparatus.

Saturation of samples. Samples of dry gas should be saturated before analysis. All expired gas samples can be assumed to be saturated at ambient temperature.

Local heating. It is of the greatest importance that the apparatus should be at a uniform temperature and not exposed to direct sunlight or placed near a radiator. During analysis, direct handling of the apparatus should be avoided as far as possible. We recommend that the operator should wear gloves and hold the analyzer for the minimum time. In spite of all precautions there is often a tendency for some part of the apparatus to become heated and errors may appear after three consecutive analyses.

Nitrous oxide. The presence of nitrous oxide will result in the indicated percentage of CO₂ being too high through physical solution of the diluent gas in the alkali. “Saturation” of the alkali with nitrous oxide is not a reliable method of avoiding this error and furthermore it will lead to an error if the same alkali is used for subsequent analyses on gas mixtures which do not contain nitrous oxide. Nitrous oxide is almost insoluble in saturated sodium hydroxide and this solution is suitable for the analysis of gas mixtures containing nitrous oxide. It is, however, necessary to alter the piston stop when the alkali is changed, as the vapour pressure is thereby altered. The analysis is more difficult to perform with the saturated solution and the results are slightly less accurate.

Sampling. Sampling techniques are outside the scope of this paper, but it is important to realize that the accuracy of estimation of the alveolar gas composition is generally limited by the sampling technique rather than the method of analysis. The Dräger analyzer can be used for samples collected manually by the method of Inkster and Rees (1956) or automatically by the method of Nunn and Pincock (1957). The sampling cylinder can probably be used for sampling directly although this would require some manual dexterity.

SUMMARY

The accuracy of the Dräger CO₂ analyzer has been examined. Factors affecting the setting of the zero adjustment have been investigated and the error due to nitrous oxide in the gas samples has been assessed. A method has been suggested whereby it is possible to analyze a mixture which contains nitrous oxide.

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REFERENCES


